Beschta, R.L. 1983. Sediment and organic matter transport in mountain streams of the Pacific Northwest. pp. 1-69 to 1-89. IN: Proceedings of the D.B. Simons Symposium on Erosion and Sedimentation, Simons, Li & Assoc., Ft. Collins, CO.

RP 570

SEDIMENT AND ORGANIC MATTER TRANSPORT IN MOUNTAIN STREAMS OF THE PACIFIC NORTHWEST

Robert L. Beschta[1]

ABSTRACT: Water quality and channel morphology characteristics are strongly influenced by the transport of sediment and organic matter in mountain streams; results are presented for two streams in western Oregon and another in southeast Alaska. The high variability of suspended sediment concentrations typical of Pacific Northwest streams is affected by several factors; these include flow magnitude, hydrograph characteristics and the sequence of storm events. Suspended sediment concentrations often show pronounced hysteresis and seasonal flushing, indicating temporal changes in sediment availability are an important feature of streams draining forested catchments. A simple suspended sediment concentration model is presented which incorporates the interaction between streamflow and suspended sediment supply. Bedload transport rates, measured with a modified Helley-Smith bedload sampler, show large temporal variability during periods of stormflow. Similarly, transport rates measured at two locations along a channel typically exhibit high spatial variability and indicate that local changes in channel storage may be responsible for much of the variability in measured bedload transport. These streams also export large amounts of organic matter during high flows. Most organic matter is transported in suspension, however, much of the particulate organic matter (particles > 0.2 mm) is transported within 7.5 cm of the bed.

INTRODUCTION

Precipitation which falls on forested watersheds of the Pacific Northwest is routed to the channel network mainly as subsurface flow. Sediment inputs to channels are primarily from mass soil movements such as slumps, debris avalanches, and soil mantle creep; input rates can often be accelerated by management activities (logging, fire, road construction, etc.). Once sediment has arrived at the channel, its routing through the stream system is largely controlled by flow conditions and channel characteristics (1).

The downstream movement of both sediment and organic matter is an important feature of mountain streams. Hence, an improved understanding of

---

[1] Associate Professor of Forest Hydrology, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331.

transport processes is requisite to evaluating impacts associated with natural and man-caused changes in sediment availability. In the Pacific Northwest, streams are also noted for their high value fisheries resources. Sediment transport can greatly alter the productivity of these aquatic ecosystems by modifying, for example, the amount and quality of spawning gravels and rearing habitat (2). This paper presents the results of several sediment transport studies conducted in low-elevation mountain streams of the Pacific Northwest. Two of these streams (Flynn Creek and Oak Creek) are located in the Coast Range of western Oregon, the third (Trap Bay Creek) is in southeast Alaska.

STUDY AREAS

Climatic characteristics for the three study areas (Table 1) are largely influenced by marine air masses which move inland from the Pacific Ocean. Winters are typically wet and cool with the vast majority of annual precipitation occurring from October through March. Most winter precipitation results from long duration, low intensity frontal storms, however, periods of moderate-to-high precipitation intensity may occur within any given storm. Because all three watersheds are relatively low in elevation (Table 1), rain is the predominant form of winter precipitation. Streamflow responses are rapid.

Table 1. Watershed location and characteristics.

Watershed	Location	Drainage area (km^2)	Elevational range (m)	Average Annual precipitation (mm)
Flynn Creek	Oregon Coast Range 44° 32' N. lat. 123° 51' E. long.	2.2	180-400	2300
Oak Creek	Oregon Coast Range 44° 37' N. lat. 123° 20' E. long.	7.5	150-660	1500
Trap Bay Creek	Chichagof Island, southeast Alaska 57° 44' N. lat. 135° 2' E. long.	13.5	0-1320	2400

All three watersheds are densely forested. Stands of 100- to 200-year old Douglas-fir (*Pseudotsuga menziesii*) on hillslopes are common at Flynn Creek and Oak Creek with red alder (*Alnus rubra*) found throughout the riparian zone. At the Trap Bay watershed, Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) predominate, with scattered western red cedar (*Thuja plicata*) and red alder common along channels and occupying moist sites. Understory vegetation is normally dense on all three watersheds. The heavy vegetative cover, along with a well developed litter layer provides protection from surface erosion processes.

Geology, soils and channel sediments vary considerably between the three watersheds. The Flynn Creek watershed is underlain by a rythmically bedded sandstone and siltstone formation which is subject to rapid attrition. Soils in this watershed are thus derived from a predominantly sandstone parent material that has a moderate to high potential for mass soil erosion. Bed material in the channel is also sandstone, which rapidly weathers or mechanically abraids to sand-sized particles; cobbles 10-50 mm in diameter typically comprise a loose armor layer overlying mostly sand-sized bed material. At Oak Creek, the underlying bedrock is predominately basalt which weathers into a clay-loam soil. Streambed sediments along the main channel are heterogenous mixtures of gravel, sand and silt, overlain by a distinct armor layer with particles averaging 50-100 mm. Bedrock at the Trap Bay watershed is largely graywacke, however, soils at elevations below 500 m have often developed on compacted glacial till. High organic components are also common in the soils on this watershed. Streambed composition is highly variable and mostly includes particle sizes ranging from fine sands to medium cobbles (0.5-150 mm). Channel gradients generally average less than 2% in the lower portions of al three watersheds.

Although mass soil movements represent the major mechanism for sediment inputs to the channel system, subsequent routing of these materials is largely influenced by channel characteristics and local changes in storage (scour and fill) along the channel bed and banks. For example, the woody root systems of streamside vegetation and the occurrence of large organic debris (large branches, boles and root wads) are important features of these streams and have a significant effect on the downstream storage transport of sediment (particularly bedload) through the channel. In some instances, large organic debris accumulations may control the spatial distribution of pool-riffle [illegible] and thus obscure any tendency towards a more systematic occurrence [illegible] channel features.

[illegible] the Oak Creek drainage had been logged by the early 1900's. The [illegible]ire drainage was commercially thinned in the early 1960's and several areas totalling less than 0.4 km^2 were clearcut between 1963 and 1969. The watershed has approximately 9 km of road. Management activities have probably had a minimal effect on the results presented herein. Both Flynn Creek and Trap Bay watersheds, are undisturbed drainages.

METHODS

Suspended sediment samples were obtained with stage-activated pumping samplers (3) at Flynn Creek and Oak Creek. Sampling was initiated by rising flows; hourly samples were obtained by combining subsamples collected at 30-min intervals. Standard filtration and gravimetric techniques for suspended solids (4) were employed to determine concentrations.

A hand-held Helley-Smith bedload sampler with a 7.5 cm square orifice was employed at all three sites. However, bag surface area was increased from a standard 1950 cm^2 to nearly 6,000 cm^2 in order to minimize plugging of the 0.2 mm mesh with fine sand and particulate organic matter (5). At both Flynn Creek and Oak Creek, most sampling was conducted at channel locations rectangular control sections (6, 7); excellent contact between the sampler and the bed was thus assured. Additional measurements at an upstream location in Flynn Creek were conducted on a natural streambed; measurements at Trap Bay Creek were on natural streambeds. All sampling was conducted from temporary bridges to prevent bed disturbance. Samples from the Helley-Smith sampler were dried at 105°C, weighed and heated to 320°C to burn off organic materials. After reweighing and seiving, both inorganic (bedload sediment) and organic (particulate organic matter) transport rates were calculated.

RESULTS AND DISCUSSION

Suspended Sediment.--Potential sources of suspended sediment could include erosion and sloughing of bank sediments, the scouring of deposits in pools and the release of suspended sediment from riffles undergoing scour. In addition, the periodic inputs from hillslope sources (mass failures) indicates an extremely complex input function would be necessary to describe the availability of suspended sediment during high flows. Because of the non-point nature of suspended sediment supplies throughout the channel system, discrete storage locations are not easily identifiable. Furthermore, individual hydrologic events and their distribution in time provides an almost infinite variety of interactions between sediment supplies and flow, and the resultant concentrations measured at the mouth of a watershed. In spite of this complexity, intensive sampling of suspended sediment and the analysis of suspended sediment concentration (C) vs. streamflow (Q) relationships (i.e., rating curves) for a large number of runoff events has indicated several patterns of response can be identified:

(I) An order-of-magnitude (or even greater) range in concentration is common at any specific flow level when samples have been obtained over a series of storm events and years.

(II) During a given runoff event, concentrations during the rising lim are typically greater than those measured during a falling limb.

(III) Periods of rapidly increasing flows tend to have higher concentrations than when flows increase at a slower rate. Hence the slo of the rising limb (dQ/dt, where t is time) affects measured concentrations.

(IV) Each succeeding runoff event will tend to have higher pe ment concentrations as long as the flows exceed those preceding runoff events.

(V) Once the maximum streamflow has occurred during a given winter, succeeding flow events will have relatively low concentrations.

(VI) Between storms, natural background levels of suspended sedime concentrations are low, usually less than 10 mg ℓ^{-1}.

Many of the above response patterns may also be characteristic of streams draining forested catchments in geographic-climatic provinces outside of th Pacific Northwest.

Sediment rating curves of the form $C = aQ^b$ where $\underline{a}$ and $\underline{b}$ are regression coefficients have been used extensively by researchers and practitioners to establish relationships between concentration and streamflow. However, in the response patterns identified above, (I) indicates that the variability of such relationships will generally be large, again emphasizing the multitude of factors affecting instantaneous concentrations. For example, suspended sediment rating curves for Flynn Creek and Oak Creek, based on 3- and 5-years, respectively, of sampling during storm events, are shown in the following tabulation:

Flynn Creek (1978-80)	Oak Creek (1976-80)
$C = 66\ Q^{0.96}$	$C = 56\ Q^{0.71}$
$r^2 = 0.36$	$r^2 = 0.29$
$n = 345$	$n = 791$

Even though flow is recognized as an important factor affecting sediment transport, in the above examples it explains less than 40% of the variation in measured concentrations.

Response patterns (II) through (V) suggest that, even though sediment rating curve data may give the impression of a chaotic system, concentrations are responding in a systematic and somewhat predictable manner. For example, (II) has been observed in a wide variety of stream systems outside of the forested watersheds in the Pacific Northwest. Furthermore, if the suspended sediment sampling is sufficiently intensive over time, individual data points may be connected on a concentration vs. streamflow scatter diagram. The result is often a pronounced hysteresis effect which indicates a relatively high availability of suspendable sediment during rising flows. Such a loop also indicates that maximum concentrations usually occur prior to the hydrograph peak. An example of a hysteresis loop (dashed line) is illustrated in Fig. 1 for the third storm of the winter. In many instances, concentrations at the hydrograph peak may be less than half of the peak concentrations measured during rising limb conditions.

When rain is falling on a forested watershed and streamflow is increasing, the variable source area concept of runoff generation indicates that stream systems are rapidly expanding (a headward expansion of active channels as well as increased wetted perimeter throughout the existing channel) in mountain watersheds (7, 8). If the channel represents the immediate source of suspendable sediment, then additional sources of supply are being accessed by the stream system as it expands. In addition, increased shear stress along the streambed and banks as flows increase, the rearrangement of floatable and large organic debris, and other factors, would operate to increase sediment availability. Even though the total amount of available sediment might be identical for two separate storms, that storm which causes the most rapid rise in flows would tend to have higher measured concentrations because it is "accessing" the available supplies at a more rapid rate. If flows increased slowly, suspended sediment tends to be transported downstream and out of the watershed relatively quickly in comparison to the rate at which

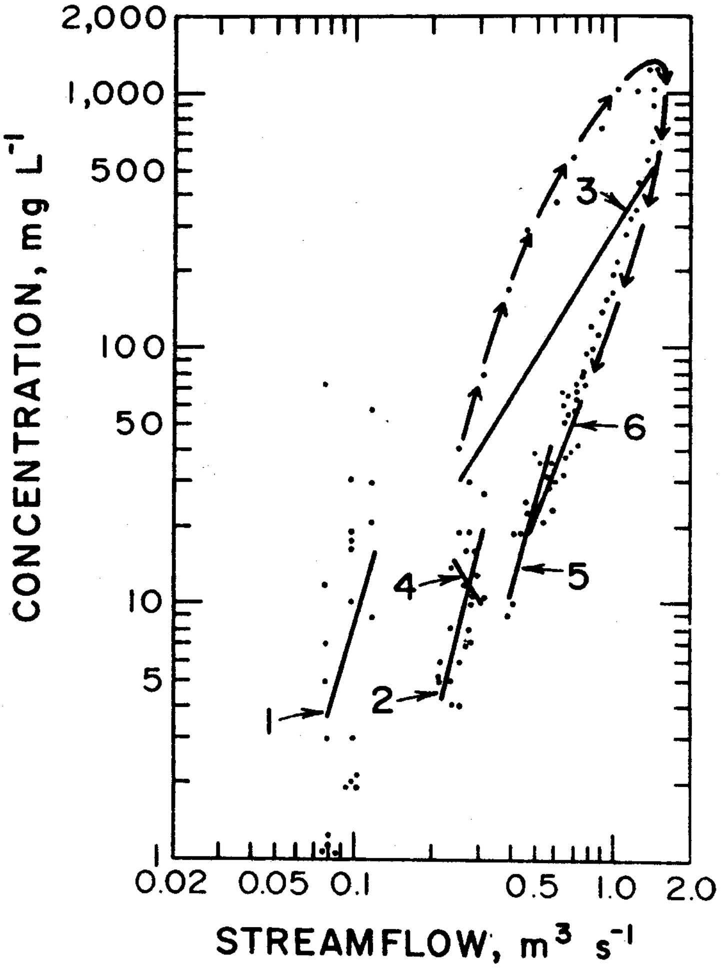

FIG. 1. - Rating curves of suspended sediment concentration vs. streamflow for 6 runoff events at Flynn Creek, 1979 water year.

new supplies become available. In this latter situation concentrations would remain relatively low, as indicated by pattern (III), even though both storms might have identical peak flows and total sediment yields.

Response patterns (IV) and (V) indicate that the sequence of storm events also influence measured concentrations during storm runoff. Concentrations measured during storms which occur prior to the yearly peak flow will tend to be higher than those which follow. This can be demonstrated by a seasonal shift in rating curves of individual storms and rating curves of monthly averages (10), or in cumulative sediment yield vs. cumulative streamflow (11). Fig. 2 illustrates the variability in concentrations and rating curves experienced for individual runoff events. This figure also shows a general shift in rating curves downward and to the right as the runoff season progresses. Similarly, a series of runoff events with hydrograph peaks of the same magnitude will generally have reduced sediment concentrations associated with each successive runoff event (12). Thus, concentration levels measured during a storm are influenced not only by conditions during the storm but also the previous history of runoff events. The combination of response patterns (II) through (V) all interact to create the situation summarized in (I). Large variability in concentrations, when expressed in the form of a rating curve, should be expected for streams draining forested mountain watersheds in the Pacific Northwest, and elsewhere.

The low levels of suspended sediment in transport between storms, as indicated by (VI), can be illustrated by considering turbidity measurements at Flynn Creek and Oak Creek (13). In both streams, turbidity can be used as a surrogate variable to index suspended sediment concentrations. An analysis of 10 storms at Flynn Creek, with peak flows ranging from 0.6 to 2.6 m^3 s^{-1}, indicated turbidities decreased to less than 30 ntu's (nephelometric turbidity units) within 14 hours after the hydrograph peak; 8 storms were actually less than 30 ntu's within 6 hours of peak streamflow. An analysis of 24 storms at Oak Creek, with peak flows ranging from 0.8 to 4.7 m^3 s^{-1}, showed 71% of the storms had turbidities less than 30 ntu's within 12 hours; 96% within 24 hours of the hydrograph peak. Results demonstrate that both streams return to relatively low turbidity levels (and suspended sediment concentrations) within 24 hours of peak storm runoff.

Recently, Van Sickle and Beschta (14) have presented a suspended sediment concentration model which more closely follows sediment transport dynamics than can be accomplished with the sediment rating curve approach. During a

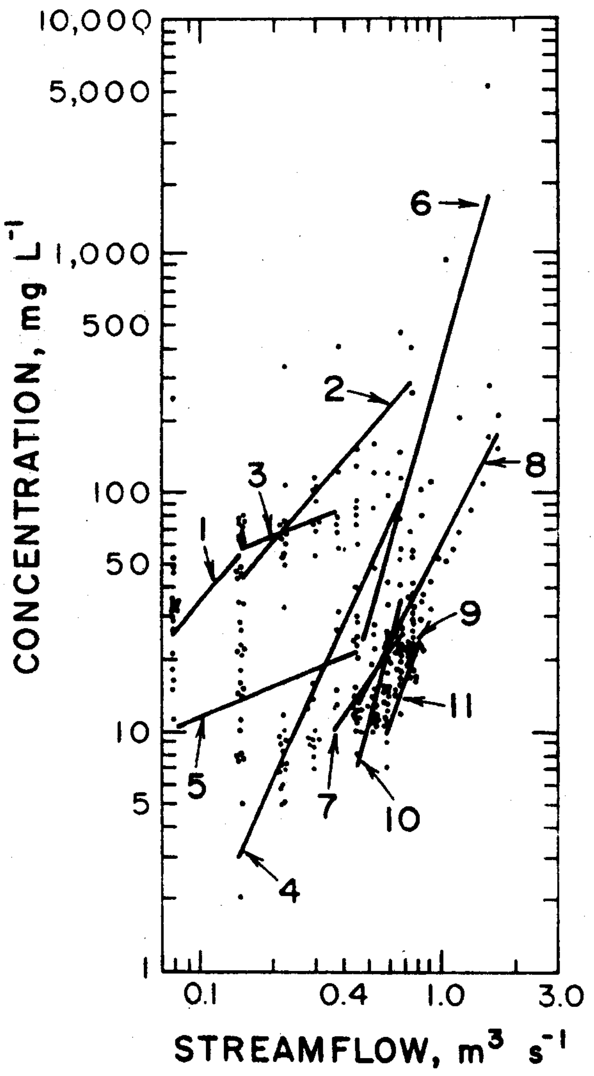

FIG. 2. - Rating curves of suspended sediment concentration vs. streamfl for 11 runoff events at Oak Creek, 1979 water year.

runoff event, sediment concentration is modeled with a sediment rating curve modified to include a washout or supply depletion function. The complete model is:

$$C(t) = aQ(t)^b \, p \, \exp[r(S(t)/S_o)]$$

in which S = sediment supply (S_o represents the initial sediment supply at the beginning of the winter runoff period). Coefficients *a* and *b* relate to channel characteristics (i.e., hydraulic geometry, channel morphology, gradient, etc.) which determine transport rates at a given streamflow and level of sediment availability. Coefficients *p* and *r* are related to factors affecting sediment availability. The single supply model has been evaluated for storm runoff at Flynn Creek and for a controlled reservoir release at Huntington Creek in Utah. A more complex distributed supply model has also been evaluated with Flynn Creek data. Both models reproduce sediment concentration dynamics of storm hysteresis and the seasonal decline in concentrations as fine sediments are flushed from the channel network. Both show promise as predictive and conceptual tools for understanding the supply dynamics of suspended sediment sources and their influence on concentrations in mountain streams.

The preceding discussion has ignored any organic component in transport. Yet, when the relative amounts of organic matter that comprise the total suspended load have been determined, the magnitude is significant. For example, analysis of "suspended sediment samples" collected from Flynn Creek and Oak Creek in 1980 indicate 20 to 40% of the material transported in suspension is organic matter (9). These results indicate that use of terminology such as "suspended sediment," when describing concentrations from forested watersheds in western Oregon and perhaps elsewhere, may be misleading and inappropriate.

Bedload Transport.--The transport of inorganic sediment (> 0.2 mm) is characterized by large temporal and spatial variability. Examples of temporal variations in transport rates during runoff events with recurrence intervals of approximately 2-5 years are shown in Figs. 3, 4 and 5 for each of the three study watersheds. Although transport rates increase rapidly with increasing flow during a storm, the highest rates measured have often occurred after the hydrograph peak. Thus, a hysteresis effect opposite to that found with suspended sediment will result. More than 75% of the total bedload discharge

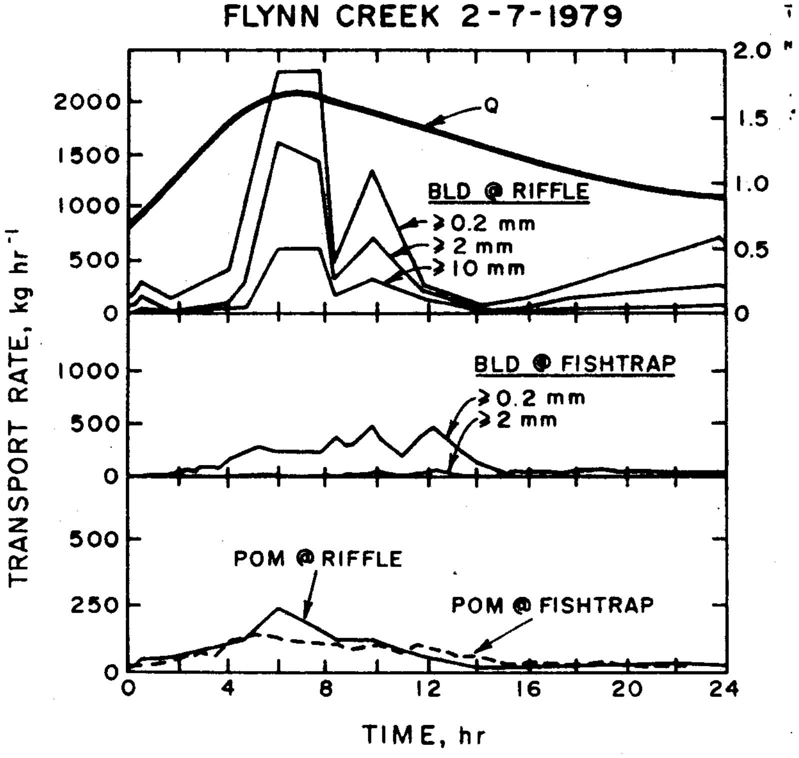

FIG. 3. - Storm hydrograph with associated bedload (BLD) and particulate organic matter (POM) transport at two sampling locations; the ri site is approximately 200 m upstream of the fishtrap site.

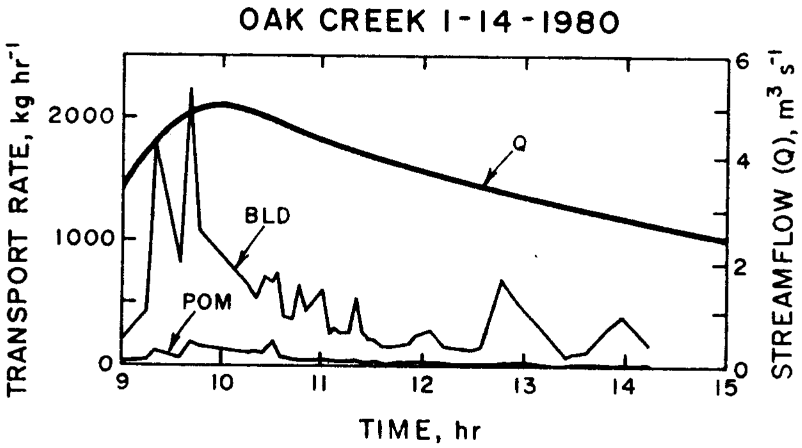

FIG. 4. - Storm hydrograph with associated bedload (BLD) and particulate organic matter (POM) transport.

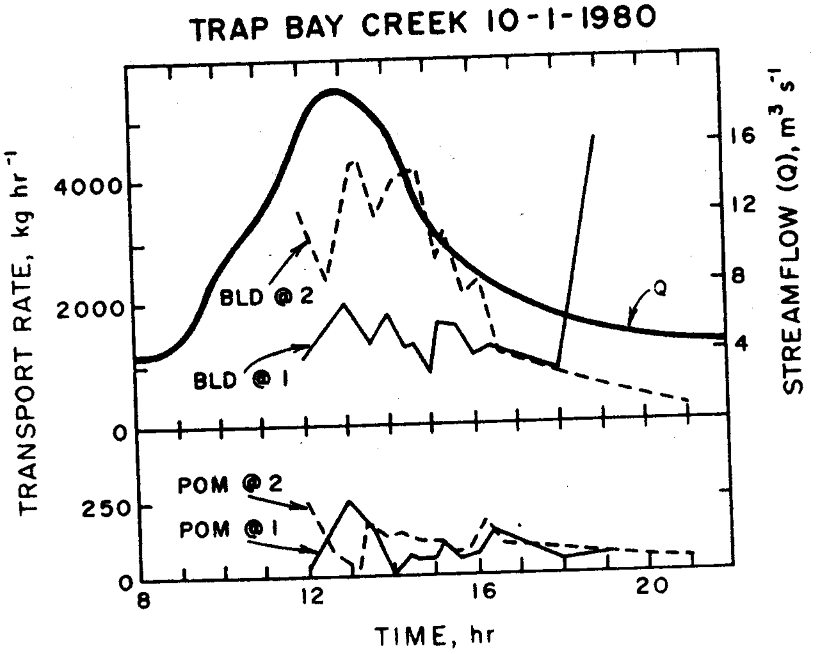

FIG. 5. - Storm hydrograph with associated bedload (BLD) and particulate organic matter (POM) transport at two sampling locations; location 1 is approximately 22 m upstream of location 2.

from a given storm can occur during the recession limb of a storm hydrograph. This is due not only to the relatively high transport rates often experienced during decreasing flows but also to the fact that streamflow recession occurs over a longer period of time.

The extent to which sampling variability with the Helley-Smith bedload sampler affects the temporal variations in transport rates (Figs. 3, 4 and 5) is not known. Jackson and Beschta (15) indicate coefficients of variation of 50 percent for replicated samples at Flynn Creek, but because the relative changes in transport rates were much greater, they concluded that the measured rates, such as shown in Fig. 3, represent real trends. In contrast, intensive sampling during a three-hour period at Oak Creek, where a sample was obtained approximately every three minutes, provides a somewhat different interpretation. Transport rates averaged 3,800-, 3,700-and 1,600-kg hr^{-1} during each hour of a three hour period (i.e., from 20 to 23 hr, Fig. 6); similar to Flynn Creek the coefficients of variation averaged 45%. However, coefficients of variation in transport rates for particles in size ranges of 0.25-0.5, 1-2, 4-8, 16-32, and > 32 mm (Fig. 6) averaged 17, 29, 58, 70, and 150%, respectively. This trend towards increasing variability at the larger particle size classes indicates that a larger mesh bag and sampler orifice are needed for larger particles in order to obtain a similar level of sampling precision characteristics of the smaller particle size classes. Increased mesh size would also greatly reduce the plugging of the Helley-Smith sample bag from organic matter and sand sized sediment. If the temporal variations in transport rates at Oak Creek (Fig. 6) are not the result of sampling variability, the alternating periods of high and low transport rates would suggest the downstream movement of "slugs," "waves" or "pulses" of bedload sediment.

Regression analysis of transport rates for the smaller particle size classes shown in Fig. 6 (0.25-0.5, 1-2, and 4-8 mm) indicate they are significantly (α = 0.10) correlated with each other. However, much of the variability in total transport can be attributed to fluctuations in the measured transport of 16-32 and the $\geq$ 32 mm sized particles. Regression analysis of the 16-32 and the $\geq$ 32 mm size classes indicates temporal fluctuations in transport rates are not significantly (α = 0.10) correlated. These relatively independent fluctuations in transport of the larger particles seem to confirm a high amount of sampling variability is producing a pattern of pseudo-cyclic changes in total bedload transport. Further research into the sampling

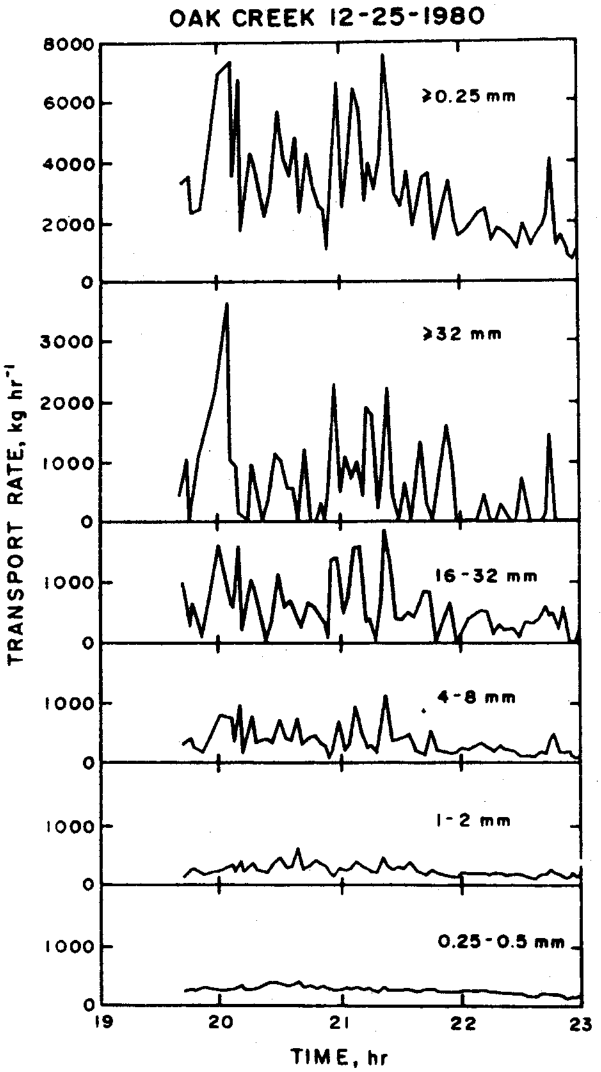

FIG. 6. - Bedload transport rates for selected particle sizes during recession limb of storm hydrograph (flows decreased linearly from 5.3 to 2.7 m^3 s^{-1} over the 4-hour period).

characteristics of the Helley-Smith sampler in natural channels is undoubtedly needed.

Results of bedload transport measurements and concurrent changes in channel cross-sections at Flynn Creek have indicated that bedload transport may occur in two relatively distinct phases (15). As flows increase, Phase I transport (consisting primarily of sand sized particles from pools, along channel margins and gravel bars, behind obstructions, and from between the larger particles that typically armor the bed) is initiated. As flows increase further, armor particles of riffles (and the underlying bed material) are entrained, marking the beginning of Phase II transport. During conditions of Phase II transport, bottom velocities through pools will exceed those of adjacent riffles; hence bedload derived from a riffle location will be carried through a pool and deposited at the next downstream riffle. During transport through the pool, finer particles would move at higher average velocities than would relatively large particles which had comprised the bed or armor layer of the upstream riffle. Thus the movement of a slug or wave of sediment through pools provides a mechanism by which sorting can take place and a reduction in the amount of fines in fresh gravel deposits may occur. Without additional inputs of fines from upstream sources, bed material composition of reworked bed material would tend to become coarser after each storm during which Phase II transport had occurred. Only when scour and fill occur can a reduction in the amount of fine sediments (sand size or smaller) be reduced.

Because the actual scour and deposition sequences of a gravel-bedded stream are sensitive to subtle changes in channel characteristics and hydraulics, and because most mountain streams have highly irregular channel geometries, predicting specific locations of scour and fill during periods of transient flow is not currently possible. Localized adjustments in channel geometry (as a result of scour and/or fill) may initiate a sequence of additional adjustments at upstream and downstream locations. Changes in channel morphology may be further initiated by random inputs of sediment and large organic debris (tree branches, boles of trees, rootwads) from channel banks and adjacent hillslopes. Although inherent sampling variability of the Helley-Smith bedload sampler may be a significant problem, the diversity of factors influencing the availability and movement of bedload sediments in mountain channels would nevertheless result in high temporal and spatial variability of transport rates.

At Flynn Creek and Trap Bay Creek, simultaneous bedload sampling at two locations along each channel have demonstrated that high spatial variability can occur. For example, at Flynn Creek, sampling was conducted at a riffle located about 200 m upstream of a fishtrap (6). The fishtrap had previously been modified to measure bedload with a vortex-tube sampler; results have been reported by O'Leary and Beschta (16). However, in this study, bedload transport was monitored at both locations with Helley-Smith samplers during the storm of February 7, 1979, illustrated in Fig. 3. Large differences in transport rates are apparent. A comparison of rating curves further illustrates the large difference in transport rates measured at the two locations:

Riffle site	Fishtrap site
$BLD = 221\ Q^{2.46}$	$BLD = 30\ Q^{4.13}$
$r^2 = 0.66$	$r^2 = 0.93$

where BLD is the transport rate of sediment > 0.2 mm (in kg hr^{-1}) and Q is streamflow (in $m^3\ s^{-1}$). Transport rates at the upstream location were nearly an order-of-magnitude greater than those measured at the main sampling site. Channel gradient at the upstream site was 0.011 but only 0.008 at the main site. The median particle diameter (d_{50}) at the upstream location was 1-2 mm whereas it averaged only 0.5 mm at the main site. Changes in channel cross-sections confirmed substantial deposition had occurred between sampling locations as a result of this storm and explains the large differences in measured transport (6).

At Trap Bay Creek, sampling was also conducted at two locations, however, these were located only 22 m apart. As shown in Fig. 5, large differences in bedload transport into and out of the 22-m section of channel are apparent indicating localized degradation (17). The cause of the large increase in transport rate at hour 19 for the upstream site (#1) is not known. The d_{50} of bedload sediments for the October 1, 1980 storm at Trap Bay Creek averaged approximately 2 mm; d50 was not significantly correlated ($\alpha = 0.10$) with streamflow.

Transport data collected at several locations along a channel and the localized scour-and-fill typically found from cross-sectional surveys indicate spatial and temporal variability is characteristic of bedload transport rates in mountain streams. The dislodging of armor particles at some critical flow may release a relatively large amount of bed material for transport downstream and r thus represent an important factor limiting the availability of bed sediments for transport (15, 18).

The median particle diameter (d50) of bedload particles sampled at the three watersheds was usually 2 mm or less indicating a preponderance of sand-sized particles in transport. Although the expanded bag size helps overcome potential plugging problems, when using the Helley-Smith sampler in streams with high sand loads (and particulate organic matter) sample times of 30 s or less are usually required during peak stormflow.

The inherent variability in particle size distributions, degree of armoring, highly variable channel geometry, transient nature of storm runoff (19) and the role of structural features such as bedrock controls and large organic debris indicate the extrapolation of equations developed under conditions of steady flow, uniform particle size and uniform channel geometry may result in large estimation errors. The development of deterministic equations that can accurately predict bedload transport in mountain streams may not be possible; perhaps a stochastic approach (20) should be emphasized.

Particulate Organic Matter Transport.--In contrast to the large temporal variability characteristic of bedload transport during storms, the transport of particulate organic matter (POM) > 0.2 mm in size was less variable and generally "in-phase" with the storm hydrograph (Figs. 3, 4 and 5). POM rates typically increased rapidly during the rising limb of a storm hydrograph, with peak transport rates occurring at or before the hydrograph peak, followed by a relatively uniform decay with time as flows recede. The general pattern of response is similar to that of the suspended sediment load, hence the supply-based model of VanSickle and Beschta (14) for suspended sediment may also have utility for simulating POM transport rates during runoff events.

During the February 7, 1979, runoff event at Flynn Creek (Fig. 3) the POM recovered from Helley-Smith samples consisted of leaves, needles, twigs, cones, and wood in various stages of decomposition, and in varying proportions. Observations during the period of increasing flow revealed that the POM fraction would, at various times, be dominated by a particular type of material. For example, needles might comprise most of the POM for several samples, then cones, and then leaf materials. During certain times, large numbers of invertebrates would also be collected in the sampler. This interesting phenomenon of a dominant type of organic material may reflect the expansion of stormflow source areas into specific upslope sites or the scouring of deposits in individual pools as flows increase. Following the hydrograph peak, a predominant type of particulate organic matter was no longer evident.

During several runoff events at Flynn Creek, POM transport rates were determined immediately below the water surface with the Helley-Smith sampler and compared with rates measured along the bed. If POM transport rates are assumed to have a logarithmic profile, measurements indicate approximately 45% of the total POM load was moving within 7.5 cm (i.e., the height of the Helley-Smith orifice) of the bed, and nearly 70% within 15 cm. Sampling was conducted when flows ranged from 32 to 52 cm in depth. Unfortunately, intermediate heights above the bed were not sampled to establish a vertical profile of transport rates. However, POM transport rates, measured with a Helley-Smith sampler placed on the bed, represent a conservative estimate of total transport by the stream. POM transport rates were usually less than 250 kg hr^{-1} at all three watersheds; POM transport was usually an order of magnitude smaller than rates of bedload transport.

In mountain streams draining forested catchments, POM export has often been overlooked as an important aspect of the total particulat yield. Yet an improved understanding of to what extent these organic particles dampen or modify turbulent flow characteristics near the bed may provide additional insights regarding the entrainment and transport of bed material in mountain streams.

SUMMARY

This paper summarizes the results of several studies conducted in western Oregon and southeast Alaska. Although the presented data are only for streams draining forested mountain catchments, the general patterns of suspended sediment, bedload and particulate organic matter transport may exist in fluvial systems draining watersheds with other climatic, physiographic and vegetative characteristics.

APPENDIX - REFERENCES

1. Pickup, G., "Stream Channel Dynamics and Morphology," in Proceedings of the Erosion and Sediment Transport in Pacific Rim Steeplands Symposium, International Association of Hydrological Sciences Publication No. 132, Christchurch, New Zealand, pp. 142-165.

2. Reiser, D. W., and Bjornn, T. C., "Habitat Requirements of Anadromous Salmonids," U.S. Department of Agriculture, Forest Service General Technical Report PNW-96, Oct., 1979.

3. schta, R. L., "Modifying Automated Pumping Samplers for Use in Small Mountain Streams," *Water Resources Bulletin*, Vol. 16, No. 1, Feb., 1980, pp. 137-138.

4. American Public Health Association, Standard Methods for the Examination of Water and Wastewater," *American Public Health Association*, Washington, D.C., 1975.

5. Beschta, R. L., "Increased Bag Size Improves Helley-Smith Bedload Sampler for Use in Streams with High Sand and Organic Matter Transport," *in* Proceedings of the Erosion and Sediment Transport Measurement Symposium, *International Association of Hydrological Sciences Publication No. 133*, June 1981, pp. 17-25.

6. Edwards, R. E., "Sediment Transport and Channel Morphology in a Small Mountain Stream in Western Oregon," thesis presented to Oregon State University, at Corvallis, Ore., in 1979, in partial fulfillment of the requirements for the degree of Master of Science.

7. Hewlett, J. D., and Hibbert, A. R., "Factors Affecting the Response of Small Watersheds to Precipitation in Humid Areas," in *Proceedings of the International Symposium on Forest Hydrology*, Pennsylvania State University, Permagon, 1967, pp. 275-290.

8. Chorleg, R. J., "The Hillslope Hydrological Cycle," in *Hillslope Hydrology*, John Wiley & Sons, 1978, pp. 1-42.

9. Beschta, R. L., O'Leary, S. J., Edwards, R. E., and Knoop, K. D., "Sediment and Organic Matter Transport in Oregon Coast Range Streams," *Water Resources Research Institute WRRI-70*, Oregon State University, Corvallis, Oregon, Feb., 1981.

10. Beschta, R. L., "Long-term Patterns of Sediment Production Following Road Construction and Logging in the Oregon Coast Range," *Water Resources Research*, Vol. 14, No. 6, pp. 1011-1016.

11. Paustian, S. J., and Beschta, R. L., "The Suspended Sediment Regime of an Oregon Coast Range Stream," *Water Resources Bulletin*, Vol. 15, No. 1, 1979, pp. 144-154.

12. Beschta, R. L., "Patterns of Sediment and Organic Matter Transport in Oregon Coast Range Streams," in Proceedings of the Erosion and Sediment Transport in Pacific Rim Steeplands Symposium, *International Association of Hydrological Sciences Publication No. 132*., Christchurch, New Zealand, Jan., 1981, pp. 179-188.

13. Beschta, R. L., "Turbidity and Suspended Sediment Relationships," *in* Proceedings of Watershed Management Symposium, *Irrigation and Drainage Division*, ASCE, Boise, Idaho, July, 1980, pp. 271-282.

14. VanSickle, J., and Beschta, R. L., "Supply-Based Models of Suspended Sediment Transport in Streams," *Water Resources Research*, Vol. 19, No. 3, 1983, pp. 768-778.

15. Jackson, W. L., and Beschta, R. L., "A Model of Two-phase Bedload Transport in an Oregon Coast Range Stream," Earth Surface Processes and Landforms, Vol. 7, 1982, pp. 517-527.

16. O'Leary, S. J., and Beschta, R. L., "Bedload Transport in an Oregon Coast Range Stream," Water Resources Bulletin, Vol. 17, No. 5., Oct., 1981, pp. 886-894.

17. Estep, M. A., "Bedload Sediment Transport and Channel Morphology of a Southeast Alaskan Stream," thesis presented to Oregon State University at Corvallis, Ore., in 1982, in partial fulfillment of the requirements for the degree of Master of Science.

18. Klingeman, P. C., and Milhouse, R. T., "Oak Creek Vortex Bedload Sampler," in Proceedings of the 1971 Hydraulics Division Specialty Conference, ASCE, University of Iowa, Iowa City, Aug., 1970.

19. Beschta, R. L., "Reviews of Theme 2; Stream Channel Dynamics and Morphology," Journal of Hydrology, New Zealand, Vol. 20, No. 1, 1981, pp. 90-93.

20. Griffiths, G. A., "Stochastic Estimation of Bed Load Yield in Pool-and-Riffle Mountain Streams," Water Resources Research, Vol. 6, No. 5, Oct., 1980, pp. 931-937.