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SEDIMENT ROUTING IN A SMALL DRAINAGE BASIN IN THE BLAST ZONE AT MOUNT ST. HELENS, WASHINGTON, U.S.A.

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Abstract

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A quantitative description of the routing of 400×10^3 t km^{-2} of sediment delivered to a 2.4 km^2 basin by the May 18, 1980, eruption of Mount St. Helens has been developed for the period May 1980-June 1981. On hillslopes this sediment resided in primary and secondary (remobilized primary) storage sites. Hillslope-erosion processes redistributed sediment on hillslopes and delivered sediment to the channel system. These processes included shallow sliding from slopes steeper than 0.70, sheet erosion, and rill erosion. The most important discrete sites of storage on hillslopes were colluvial wedges and sites upslope of logs or other organic debris.

Most tephra delivered to the basin by the eruptions is likely to be preserved in the stratigraphic record. Twelve percent of the sediment delivered to the study area was transported to the channel system directly by the eruption and by hillslope-erosion processes. Of this, approximately half remained in storage in the channel system, and the remainder was exported from the drainage basin. Important sites of alluvial sediment storage included alluvial fans, sites related to logs, channel beds and alluvial terraces.

Introduction

The May 18, 1980 eruption of Mount St. Helens provided a natural laboratory for geomorphologists interested in the processes and rates of sediment production and landscape evolution. Erosion of a distinct layer of unconsolidated tephra deposited over a steep, devegetated landscape gives an indication of (1) factors controlling rates of sediment production from the landscape, (2) response of a geomorphic system to an abrupt increase in sediment availability, and (3) the character and extent of the stratigraphic record of volcanic events that produce tephra.

The timing and rate of redistribution of tephra deposits have important implications for a variety of disciplines. The pattern and persistence of tephra on hillslopes affect the quality and extent of the tephra chronologic record, the pattern and rate of revegetation, and delivery of sediment to channels. The rate of sediment movement through a channel network controls the recovery of aquatic ecosystems, sediment delivery to downstream areas, and the tephra chronologic record in lakes (Anderson et al., 1985).

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The objective of this study was to describe the movement and storage of 1980 tephra within the study area for the first post-eruption year, following some of the principals of sediment budget studies outlined by Dietrich et al. (1982). Sediment budget analysis involved (1) identifying erosion processes and measuring their rates, (2) identifying and, where possible, quantifying controls on these processes, (3) identifying linkages between processes and sediment-storage sites, (4) quantifying the volume of sediment stored in these sites, and (5) estimating the rate of sediment yield from the watershed.

Study area

The 2.4 km^2 Boomer Creek (informal name) drainage basin is located 14 km northeast of the crater of Mount St. Helens, Washington (Fig. 1). The mainstem channel in the basin is a fourth-order (Strahler, 1957) tributary to Clearwater Creek, which drains southward into the Muddy River on the east side of the mountain. Prior to the 1980 eruption, 88% of the basin was old-growth conifer forest and the remainder had been clearcut logged. Approximately 5.2 km of narrow logging roads had been constructed in the basin before 1980.

The climate is maritime with wet, relatively mild winters and dry, cool summers. Mean-annual precipitation in the study basin is approximately 3000 mm, with 75% of the precipitation occurring between October and April, much of it falling as snow (USDA Forest Service, 1981). Rainfall intensity is moderate with 20 mm h^{-1} having a return period of about 10 years (Hershfield, 1961). Collins and Dunne (1986) summarize precipitation for 1980–1982 at a nearby site. Average daily air temperatures at Spirit Lake (elev. 974 m) range from 7° to 22°C in July and −4° to 1°C in January. Diurnal freeze–thaw occurs on most days between late October and early May (USDA Forest Service, 1981).

Like much of the eruption-affected area east and northeast of the volcano this drainage basin contains slopes with a wide range of gradients.

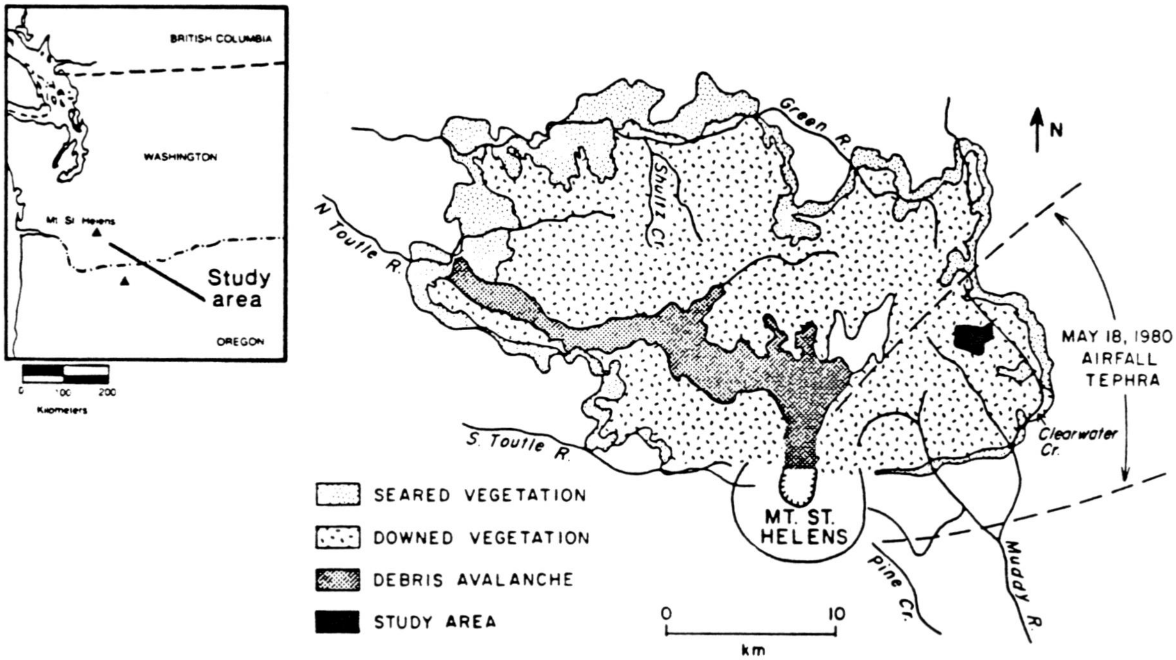

Fig. 1. Location map.

Elevations in the basin range from 730 to 1370 m. The basin contains 26.6 km of stream channel, 15.5 km of which are first-order. The drainage density is 11.1 km km^{-2}. Most channels are V-shaped in cross-section where slopes are moderate or steep, but wider and shallower where slopes are gentle. A few anomalously straight channel reaches may be fault controlled.

Volcanic events of 1980 at Mount St. Helens are described in Lipman and Mullineaux (1981). The study basin lies within the downtree portion of the blast area (Fig. 1), where pre-eruption trees were either uprooted or broken off above their bases and toppled by the force of the May 18, 1980 blast (Christiansen and Peterson, 1981). In this paper, the term "blast" refers to the directed hydrothermal explosion and to the associated pyroclastic density current of May 18, 1980 (Lipman and Mullineaux, 1981; Walker and McBroome, 1983; Waitt, 1984). Primary deposits in Boomer Creek basin from the 1980 eruptions of Mount St. Helens consist almost entirely of 17 cm of May 18 blast deposit overlain by 17 cm of May 18 airfall tephra (Waitt, 1981; Waitt and Dzurisin, 1981; Smith, 1985, pp. 20–26).

Geomorphic conditions

A preliminary assessment of geomorphic conditions in the study area one year after the May 18, 1980 eruption involved categorizing 1980 tephra on hillslopes as sediment in either primary or secondary storage. Sediment storage sites were further distinguished based on location and form of deposit, such as upslope of log or rill levee. Tephra in primary storage had remained where it was originally deposited by blast and airfall processes. The undisturbed, uniform blanket of tephra distributed throughout the study basin was a component of primary storage and was referred to as the tephra profile. Discrete primary storage sites, other than the tephra profile, were sites where tephra was deposited in recognizable, anomalously thick accumulations by the 1980 eruptions. The stratigraphic sequence in primary storage sites remained undisturbed.

Tephra in secondary storage had been transported after primary deposition and redeposited on the hillslope (Fig. 2). Secondary-storage sites were recognized by (1) two or more tephra layers that had been mixed during transport and redeposition, or (2) a deposit of reworked sediment overlying a primary (possibly truncated) tephra profile.

Primary storage sites, in addition to the tephra profile, included colluvial wedges and sites upslope of logs, small organic debris, rootwads, or stumps. Additional storage occurred within small organic-debris accumulations and in rootwad pits or other slope depressions. Secondary-storage sites included these as well as rill fans, rill levees, and disturbed profile sites containing mixed layers of tephra resulting from downslope sliding or other remobilizing processes.

Three types of erosion processes were evident in the study area: (1) shallow sliding; (2) sheet erosion; and (3) rill erosion. Shallow sliding removed virtually the entire tephra profile from many slopes steeper than 0.70, and occurred at various places in the watershed, including steep streamside areas. Much of this sliding occurred during original emplacement. On other steep slopes, tephra remained until the following wet season. Sliding adjacent to stream channels deposited tephra in the channel; other slide-transported tephra accumulated in colluvial wedges on hillslopes. Importance of shallow sliding decreased greatly after the first winter because of rapid removal of the most readily mobilized tephra.

The May 18 eruption of Mount St. Helens greatly altered hillslope hydrology in the study area. Vegetation was killed and buried by new tephra, greatly reducing interception. More importantly, tephra layers C and D (Waitt, 1981) formed an impermeable crust 1–2 cm thick, greatly decreasing surface-infiltration capacity relative to the undisturbed forest floor

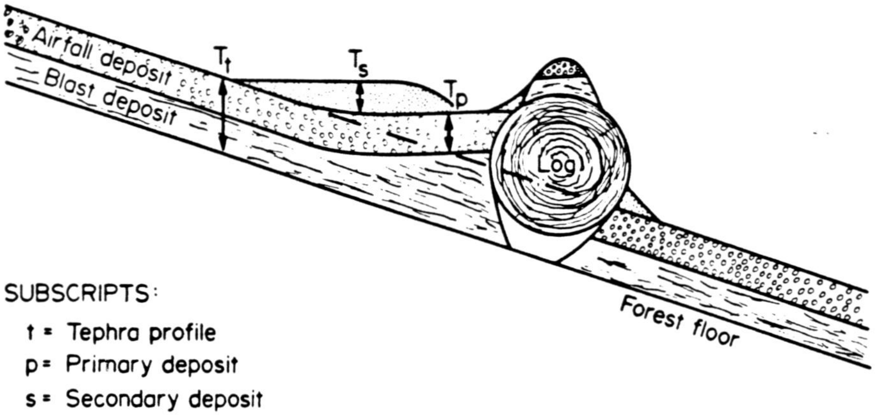

Fig. 2. Cross-section through 1980 deposits along a hillslope transect line. *T* indicates tephra thickness.

(Swanson et al., 1983). This reduction in infiltration capacity resulted in Hortonian overland flow, causing sheet and rill erosion, which had been virtually non-existent in the undisturbed, forested portions of the study area prior to the May 18 eruption.

Rapid delivery of hot tephra to the channel system probably caused rapid melting of snow along channels and high streamflows on May 18. These and other high-flow events following the May 18 eruption were indicated by the elevation of alluvial terraces and trimlines within the channels and by rapid post-eruption growth of an alluvial fan at the mainstem mouth. Stream transport of tephra occurred by ordinary, fully turbulent flow and by high-sediment-concentration flows, as indicated by sedimentary structures and texture of alluvial deposits (Smith and Smith, 1983; Smith, 1985, pp. 36–42; Smith, 1986).

Several types of alluvial sediment storage sites were evident in Boomer Creek basin. Alluvial fans and overbank deposits formed where an abrupt decrease in gradient occurred or where streamflow overtopped the channel banks. Alluvial terraces formed as remnants of deposits that once filled the entire channel width then were partially eroded by streamflow. Storage sites related to organic debris were accumulations of sediment associated with logs, rootwads, stumps, or accumulations of small debris. Large sediment dams were formed by log jams, usually with one or more logs anchored to the channel banks. These jams trapped smaller debris, resulting in more effective sediment barriers. Channel bed storage occurred in the absence of woody debris at sites of low channel gradient. Slackwater deposits formed in low-velocity, eddying current, commonly at abrupt changes in channel direction.

Methods

To measure volumes of sediment in various hillslope-storage sites, 13 sampling locations were randomly selected from a grid of points on a map of the study basin (Fig. 3). At each site, a line transect followed the fall line of the hillslope from the ridge line to the high-flow channel of the nearest stream. The type and size of sediment storage sites were noted along each transect in a downslope direction (Smith, 1985). Thickness of the total tephra profile as well as thicknesses of individual layers within the profile were measured to the nearest millimeter in pits dug at 10 m intervals along the hillslope transect lines. All measurements accounted for map projection. An overall mean and a standard error of the thickness of each unit based on cluster sampling (Murthy, 1967, p. 307) were computed. Means and standard errors of volumes of stored sediment or ero-

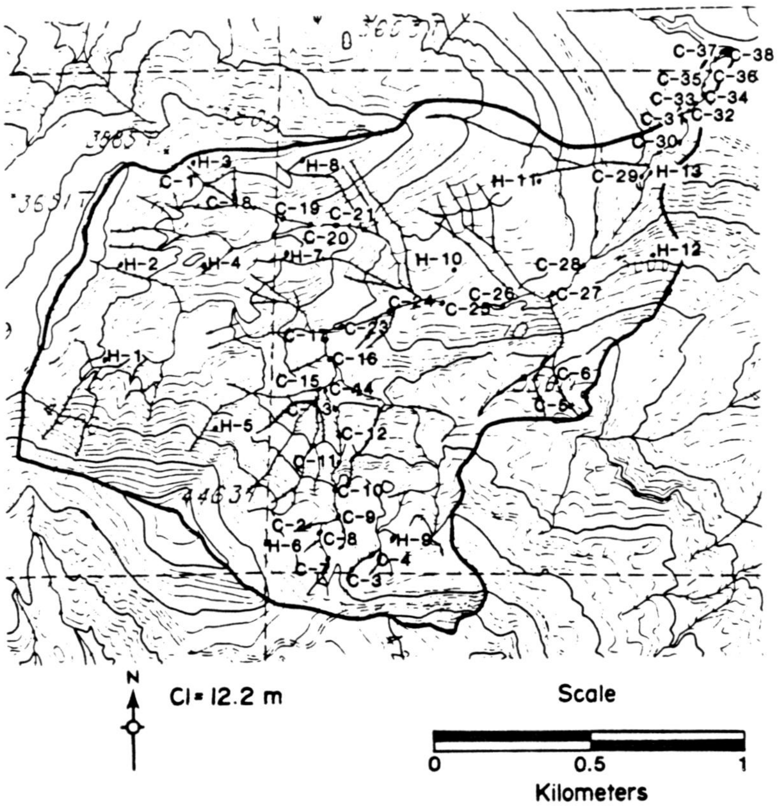

Fig. 3. Study area. Points designated by *H* or *C* indicate transects on hillslopes or in channels, respectively.

sional landforms, such as rills, were determined using equations applicable to line transect sampling (Freese, 1962, p. 19).

Bulk density determinations were made on four samples of 1980 alluvial sediment and on six samples of hillslope sediment to convert from volume of sediment to mass. The following values were obtained (g cm^{-3}): blast deposit = 1.37, airfall tephra = 0.94, surface crust = 1.07 (Collins et al., 1982), combined 1980 tephra = 1.16, and 1980 alluvium = 1.41.

The volume of tephra eroded by shallow sliding was calculated by multiplying the total surface area of affected slopes by the 34 cm average thickness of tephra delivered to the basin (Smith, 1985).

Values of sheet erosion rates were based on repeat measurements of erosion pin height above the tephra surface at eight sites in the down-tree area northeast of the volcano within the zone of coarse-pumice airfall tephra. Each site consisted of adjacent clearcut and down-tree plots (Swanson et al., 1983). Cross-sectional areas of rills were measured along lines perpendicular to the hillslope-transect lines then converted to rill-eroded volume (Smith, 1985). These lines were established at 3-m intervals downslope, extended 5 m either side of the transect line, and thereby created a 10 m wide plot, extending for the length of each transect.

The volume of sediment deposited directly into stream channels during the May 18 eruption was estimated by multiplying the water surface area at high-flow by the mean thickness of tephra delivered to the basin. Estimates of the volume of tephra delivered to channels by shallow sliding were based on the area of sliding-affected slopes adjacent to stream channels. Delivery by sheet and rill erosion was

TABLE 1

Weighted mean values of the volume of sediment in primary (V_p) and secondary (V_s) hillslope-storage sites

Site type	Number of sites	V_p ($m^3 ha^{-1}$)	V_s ($m^3 ha^{-1}$)	Total vol. ($m^3 ha^{-1}$)	S.E. of total
Colluvial wedge	—	330	59	390	58
Upslope of log	99	170	85	260	58
Disturbed profile	17	0	210	210	78
Other organic debris-related sites	16	12	22	34	16
Rootwad pit	1	4.5	0	4.5	2.5
Rill fan	3	0	2.8	2.8	3.6
Slope depression	2	0.3	1.3	1.6	1.7
Rill levees	—	0	1.0	1.0	0.6
Total		520	380	900	114

calculated as volume of sediment mobilized less volume redeposited in rill fans and rill levees before reaching the stream system. Volumes of in-channel sediment storage sites were measured along transects following the thalweg of sample stream reaches, which were generally 50 m long in first- and second-order and 100 m long in third- and fourth-order channels (Smith, 1985).

Results

Distribution of sediment

Tephra-profile thickness for thirteen hillslope transects averaged 34 cm, varying from 19 to 44 cm. A negative correlation ($r = -0.42$, $p < 0.05$) existed between thickness of the tephra profile and slope gradient. This correlation was weak, because tephra thickness also varied as a result of the effects of blast-toppled trees and channeling of the blast by topography.

Hillslope storage sites contained 900 m^3 of sediment per hectare, 58% in primary and 42% in secondary storage (Table 1). Colluvial wedges accounted for more stored sediment than any other type of hillslope storage site. Eighty-five percent of this volume was in primary storage and 15% in secondary storage (Table 1). Ninety percent of the volume of wedges was stored at the base of slopes denuded of 1980 tephra by shallow sliding.

Storage upslope of logs accounted for 29% of the total volume in hillslope storage sites (Table 1). Presence or absence of logs prior to the eruption, a function of land-use history, influenced the distribution of sediment storage on hillslopes. The total volume of sediment stored upslope of logs on transects H-3 and H-4 (clearcut prior to the eruption) was only 65 and 0 $m^3 ha^{-1}$, respectively, compared to a mean volume of 290 $m^3 ha^{-1}$ for the eleven down-tree sites.

The volume of sediment stored behind logs was positively correlated with several independent variables, including: (1) gradient upslope of the storage site; (2) size of log; and (3) divergence of log orientation from the direction of the hillslope fall line. Ninety-one percent of logs that formed storage sites occurred at an angle $\geq 45°$ relative to the fall line. A multiple-regression analysis indicated that these variables accounted for only 11% of the variation in stored sediment. Other variables that were not measured, but that appeared to influence volume of sediment deposited, included degree of log contact with the ground and log orientation relative to trajectory of the May 18 blast.

Erosion processes

Shallow sliding was the most effective process of sediment mobilization on hillslopes, removing tephra from 35.6 ha, or 15% of Boomer Creek basin. Total volume of 1980 tephra eroded by sliding was 123,000 m^3. Fifty-six percent (68,800 m^3) of this volume was redeposited at the base of hillslopes in colluvial wedges.

The mean rate of sheet erosion in four down-tree plots during the first post-eruption year was approximately 40 $m^3 ha^{-1} yr^{-1}$, corresponding

TABLE 2

Rill erosion rates in down-tree (DT) and clearcut (CC) areas

Gradient range	Area (ha)		Rate (m^3 $ha^{-1}yr^{-1}$)		Volume eroded (m^3 yr^{-1})	
	DT	CC	DT	CC	DT	CC
0.00-0.10	4.7	0.0	0.0	0.0	0.0	0.0
0.10-0.20	21.6	3.7	0.0	3.8	0.0	14
0.20-0.30	27.1	6.9	0.8	19	21	130
0.30-0.40	25.3	6.9	4.1	46	100	320
0.40-0.50	25.6	5.5	9.8	84	250	460
0.50-0.60	19.6	2.5	18	130	350	330
0.60-1.00	42.9	2.5	43	200	1800	500
Total	168	28.0	15	64	2500	1800

to downwearing of 4 mm over the plot (Swanson et al., 1983). Rates of sheet erosion in four sampled clearcut plots were not significantly different from down-tree sites (Swanson et al., 1983). The 40 m^3 $ha^{-1}yr^{-1}$ rate was therefore applied to the total area in Boomer Creek basin, less the area of stream channels and sliding-denuded hillslopes, yielding a volume of 7800 m^3 of removed sediment. Because the drainage density of rills was much greater than that of channels, sediment removed from inter-rill areas was assumed to have entered the rill system.

Rate of rill erosion for the hillslope plots varied from 0 (no rills present) to 110 m^3 $ha^{-1}yr^{-1}$. Two of the sites with highest rate (H-3 and H-4) were the only clearcut plots, suggesting that rate might have been higher in clearcut than in down-tree areas (Table 2). Rate increased significantly with slope gradient; the increase was greatest in clearcut areas (Fig. 4).

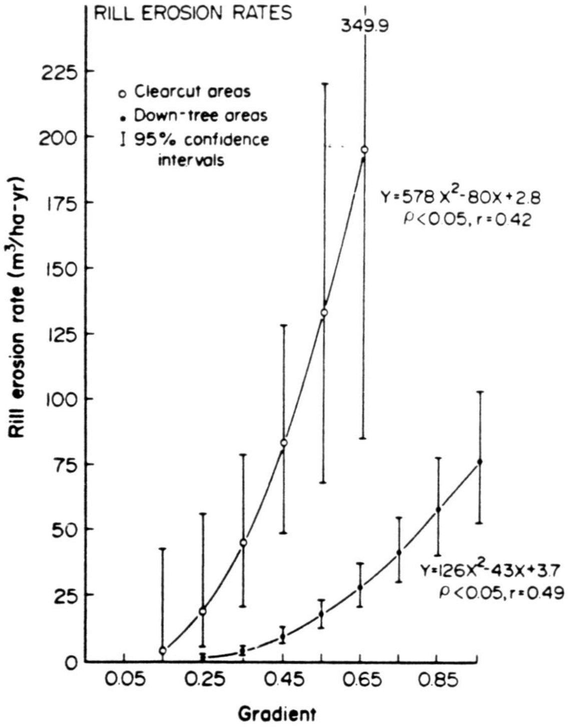

Fig. 4. Variation of rill-erosion rate with gradient in down-tree (solid circles) and clearcut (open circles) areas. Vertical lines represent 95% confidence interval estimates.

Low correlation coefficients for the regressions of rill erosion rate as a function of gradient (Fig. 4) indicate that most of the variation in rate was attributable to variables other than gradient. Adding slope length as an independent variable increased the value of the correlation coefficient to 0.50 for down-tree areas and 0.77 for clearcut areas. The greater influence of slope length in clearcut areas was probably due to less influence of down logs on clearcut hillslopes. Downtrees diverted rill flow across slope, reducing gradient of the flow path and flow velocity. Only in three of thirteen hillslope plots did rills cut into pre-1980 soil and tephra layers, accounting for 2.5% of the total volume of rill-eroded sediment.

Shallow sliding was the dominant process of sediment delivery to channels because steep slopes bordered many segments of the channel network (Table 3). Other important mechanisms included direct deposition from the eruption and sheet and rill erosion. The rate of sediment delivery to channels decreased following the first post-eruption year, because most of the 1980 tephra that was prone to sliding was mobilized during the first year and rates of surface erosion decreased dramatically in

TABLE 3

Delivery of sediment to channels

Process	Volume delivered to channel (m^3)
Direct deposition	38,700
Shallow sliding	54,200
Sheet and rill erosion	10,000
Total	103,000

subsequent years (Collins et al., 1983; Swanson et al., 1983; Collins and Dunne, 1986).

Sediment storage in channels

Channel characteristics and volume of sediment in various storage sites were measured in selected reaches of the four channel orders (Tables 4 and 5). These volumes do not include deposits of colluvium within the high-flow channel. In first-order channels the greatest storage volume was in channel-bed storage. Debris-related storage accounted for 31% of the alluvial sediment in first-order streams (Table 4). About half of this volume was accountable to single logs (Table 5).

As in first-order channels, the greatest storage volume in second-order channels was in channel-bed storage, reflecting the relatively low importance of alluvial fans and log jams (Tables 4 and 5). Organic debris-controlled storage was less important in second-order than in first-order channels, in part because of the difference in alluvial fan storage (Table 4). Furthermore, second-order channels were more deeply incised than first-order, causing a greater

TABLE 4

Alluvial sediment in channel-storage sites. For each storage site, values in descending order are: (1) sediment volume per unit length of sampled channel; (2) sediment volume in all channels of that order; and (3) percentage that volume represents of the stored sediment in each stream order

Stream order	Sampled channel length (m)	Total channel length (m)	Alluvial fans (m^3 m^{-1}) (m^3) (%)	Log or debris related (m^3 m^{-1}) (m^3) (%)	Bed (m^3 m^{-1}) (m^3) (%)	Alluvial terraces (m^3 m^{-1}) (m^3) (%)	Other (m^3 m^{-1}) (m^3) (%)	Total (m^3 m^{-1}) (m^3) (%)
1	379	15,500	0.004	0.11	0.15	0.05	0.04	0.36
			62.0	1700	2300	780	620	5500
			1	31	42	14	11	100
2	464	6600	0.24	0.17	0.40	0.10	0.005	0.92
			1600	1100	2600	660	33	6100
			26	19	44	11	0.5	100
3	384	2340	0	1.4	0.11	0.50	0.60	2.6
			0	3300	260	1200	1400	6100
			0	54	4	19	23	100
4	1190	2240	5.8	1.6	0.13	0.55	0.04	8.1
			13,000	3600	290	1200	90.0	18,000
			72	20	2	7	0.5	100
All channels		26,700						
Vol. (m^3)			15,000	9700	5400	3800	2100	36,000
(% total)			42	27	15	11	6	100

TABLE 5

Distribution of sediment volumes in debris-related storage sites

Channel order	Single log (m^3) (%)	Log jam (m^3) (%)	Small debris (m^3) (%)	Other (m^3) (%)	Total (m^3) (%)
1	930	0	620	160	1700
	54	0	36	9	100
2	200	230	660	33	1100
	18	20	59	3	100
3	370	2500	310	94	3300
	11	76	10	3	100
4	1100	2200	250	2	3600
	31	62	7	0.1	100
Total (m^3)	2600	4900	1800	330	9700
(%)	27	51	19	3	100

tendency for logs to span second-order channels without influencing sediment movement.

Logs and log jams accounted for a larger proportion of sediment in debris-related storage sites in third and fourth-order channels than in smaller streams (Table 5). Log jams formed more frequently in larger channels where higher discharge transported logs to channel constrictions or where one or more stable logs blocked the channel. The most important type of storage site in fourth-order streams was alluvial fans. The single, 11,000 m^3 fan at the mouth of Boomer Creek strongly affected the relative importance of different types of storage sites.

Total alluvial-sediment storage increased exponentially with stream order. This increase was caused by several factors including: (1) transport of sediment from low- to high-order channels; (2) increase in channel size, and

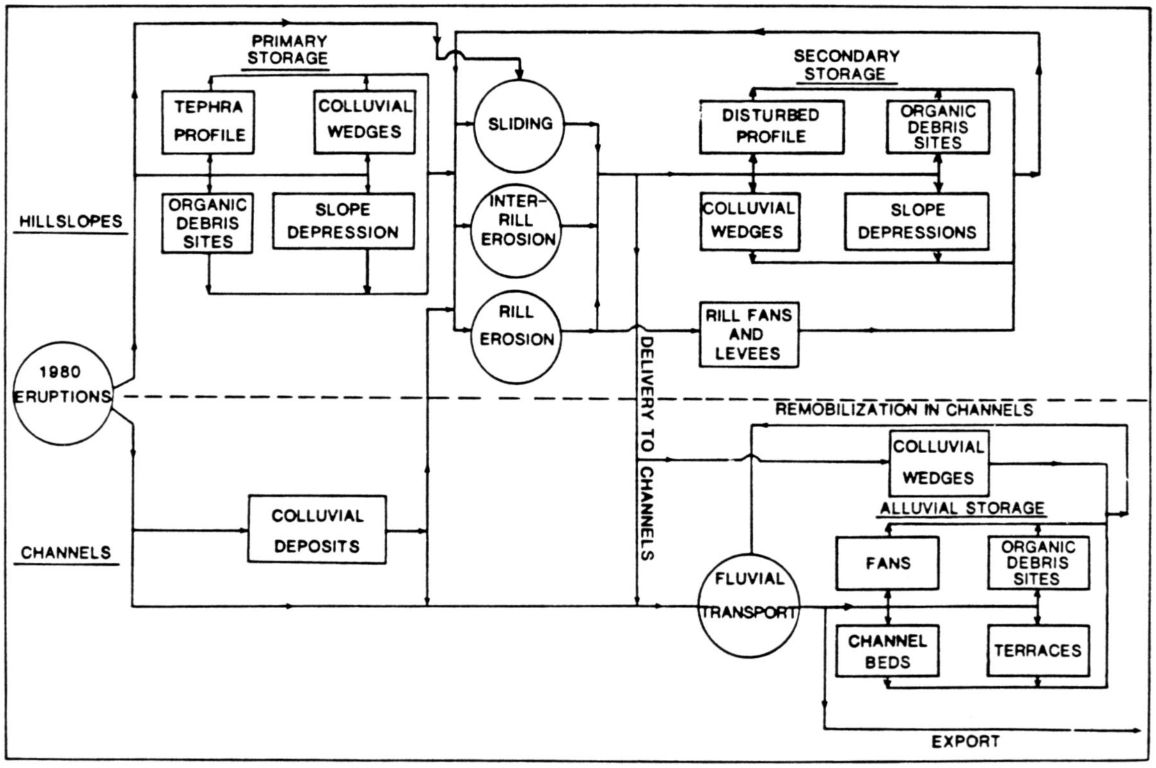

Fig. 5. Flow chart illustrating the routing of the 1980 tephra. Hillslopes are represented in the top portion of the diagram, and channels in the bottom portion. Circles represent transfer processes; rectangles represent storage elements; lines represent linkages between transfer and storage; arrows show the temporal sequence of processes; bridges indicate unconnected linkages.

therefore storage capacity with increasing order; and (3) increase in the number of large-volume storage sites such as log jams and alluvial fans. The distribution of sediment among the tributaries and the mainstem indicated that much of the downstream movement of 1980 tephra had already occurred by summer, 1981. Fifty-one percent of all alluvial sediment was stored in the mainstem, which accounted for 28% of the total channel area.

Several variables affected the volume of sediment storage in channels. Upstream drainage area and mean channel gradient accounted for less than half the variation in alluvial storage. Other important factors were effects of large organic debris, channel morphology, and character of the drainage network. Effect of land use was unclear because no fourth-order reaches and only one sampled third-order reach had been clearcut. Therefore, in the higher-order streams where most sediment was stored, valid comparisons could not be made.

Sediment budget

The above accounting of sediment delivery, mobilization, production, storage, and yield in the study basin for 1980–1981 is summarized as a sediment budget (Fig. 5 and Table 6). Ninety-five percent of the total mass of 1980 tephra was delivered to the hillslopes. The remainder was delivered to the channel system directly by the eruption. After one year, 79% of the 1980 tephra was unaffected by erosion. Sixteen percent was remobilized on hillslopes. Nine percent was redeposited on hillslopes and 7% was delivered to channels by erosion processes. One year after the May 18 eruption, 88% of the 1980 tephra remained on hillslopes in the Boomer Creek basin. Six percent was stored within the channel system and 6% was exported from the watershed (Table 6).

Discussion

Most of the tephra delivered to the study area by the 1980 eruptions may be preserved in the stratigraphic record. After one year, 88% of the tephra remained on hillslopes in the study basin. Rates of sheet and rill erosion decreased dramatically with time as a result of increased infiltration capacity, reduced overland and rill flow, and armoring of the surface (Collins et al., 1983; Swanson et al., 1983; Collins and Dunne, 1986). The frequency of debris slides in pre-1980 soil has continued to exceed pre-eruption rates for several years as a result of loss of root shear strength caused by uprooting of trees by the May 18 blast (Swanson, unpublished data). However, in much of the blast zone debris slides have not had a widespread effect on tephra removal.

One-half of the 1980 sediment delivered to the channel system remained in channel storage sites at the end of the first post-eruption year. Some of these sites, notably the large fan at the mouth of the basin, terraces, and sediment stored by large logs, may store sediment for many decades.

Results of this study can be compared with erosion studies conducted by Collins et al. (1983) north of Mount St. Helens covering 352 km^2 of the Toutle River drainage basin, which experienced the directed blast but not airfall of coarse pumiceous tephra. Collins et al. (1983) estimate that 87% of the tephra delivered to the Toutle River basin remained on the hillslopes one year following the 1980 eruptions; 88% remained in Boomer Creek basin (Table 7). Shallow sliding was an important process of sediment delivery to channels in Boomer Creek basin, but in the Toutle basin study area, only delivery by water erosion was important (Collins et al., 1983). Water erosion accounted for only 9 percent of the sediment delivery to channels in Boomer Creek basin. Furthermore, in the Toutle basin study area only negligible storage of mobilized sediment occurred on hillslopes or in channels, while such storage was a very important component of sediment routing in Boomer Creek basin. Studies by Lehre et al. (1983) in a 764 km^2 area of the Toutle River basin account for erosion and sediment storage

TABLE 6

Sediment budget, May 1980–June 1981

Budget element	Mass (t)	Percent of total mass delivered by 1980 eruptions
Delivery of sediment directly by 1980 eruptions		
to hillslopes	922,000	95
to channels	44,900	5
Total	967,000	100
Remobilization of sediment on hillslopes		
shallow sliding	143,000	15
sheet erosion	8300	0.9
rill erosion	5000	0.5
Non-remobilized sediment on hillslopes	766,000	79
Eruption-delivered sediment to channels	44,900	5
Total	967,000	100
Destination of hillslope remobilized sediment		
redeposition on hillslopes	82,400	9
delivery to channels		
shallow sliding	62,900	6
sheet and rill erosion	11,000	1
Non-remobilized sediment on hillslopes	766,000	79
Eruption-delivered sediment to channels	44,900	5
Total	967,000	100
Location of sediment, June 1981		
tephra profile	644,000	67
other hillslope primary sites	118,000	12
hillslope secondary sites	85,800	9
in-channel sites	59,000	6
sediment yield	60,000	6
Total	967,000	100

on the large debris avalanche in the North Fork Toutle River. Shallow sliding removed tephra from 5.5% of this area (Lehre et al., 1983) compared with 15% of Boomer Creek basin.

TABLE 7

Comparison with Toutle River basin studies (Collins et al., 1983)

	Boomer Creek	Toutle River
Basin area (km^2)	2.42	352
Mass of 1980 tephra deposited ($\times 10^3$ t km^{-2})	400	260
Delivery to channels by erosion (volume percent)	8	13
Rate of sediment export ($\times 10^3$ t km^{-2} yr^{-1})	25[a]	34[b]
Mass retained on slopes in summer 1981 (%)	88	87

[a] Including 36 t km^{-2} yr^{-1} of pre-1980 colluvium.
[b] Including 2.9×10^3 t km^{-2} yr^{-1} of pre-1980 colluvium.

The contrast between the model of sediment routing presented in this study with those by Collins et al. (1983) and Lehre et al. (1983) in the Toutle basin point out variation in the absolute and relative rates of erosion processes in the blast zone at Mount St. Helens. This variability results from differences in eruption effects, quantity and texture of deposits, slope gradients, physiography, and pre-eruption land use (Collins et al., 1983; Swanson et al., 1983).

It is difficult to compare the observations at Mount St. Helens with erosion following eruptions elsewhere, because of major differences in the type and timing of volcanic events, their eruptive products, and other natural factors, as well as differences in types and scales of study methods. A notable feature of the 1980 Mount St. Helens activity is the predominance of a single, brief emplacement of tephra over a wide area. Other volcanoes where erosion research has been conducted have erupted over a period of many months, and even years, frequently altering the texture and hydrology of surface deposits, such as occurred at Paricutin (Segerstrom, 1950), Irazu (Waldron, 1967), and Sakurajima (Shimokawa and Taniguchi, 1983).

Summary

The 1980 eruptions of Mount St. Helens delivered 400,000 t km^2 of tephra to the study basin. The sudden influx of this large amount of sediment initiated an immediate geomorphic response. After deposition, 15% of the 1980 tephra was mobilized by shallow sliding on hillslopes exceeding a critical gradient. The 1980 tephra was capped by a silty layer of low infiltration capacity, causing rain to runoff as sheet flow, eroding an average 4 mm of the surface within the first post-eruption year. Sheetflow became channelized into rills where additional sediment was mobilized. Rates of sheet and rill erosion decreased through time because of an increase in infiltration capacity and exposure of coarse, less erodible substrates (Herkelrath and Leavesley, 1981; Swanson et al., 1983; Collins and Dunne, 1986).

Most remobilized sediment on hillslopes was redeposited before reaching the channel system. However, in addition to the 5% of the tephra mass delivered directly to channels by the eruption, 7% was delivered by shallow sliding and sheet and rill erosion. Sediment accumulated in channel storage sites such as those formed upstream of logs felled by the eruption. A large alluvial fan formed at the mouth of Boomer Creek and accounted for nearly one-third of the channel-stored sediment after one year. By this time, 6% of the 1980 sediment delivered to the basin was in storage within the channel system and 6% had been exported from the basin. Most of the tephra delivered to the basin by the 1980 eruptions is likely to be preserved in the stratigraphic record.

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