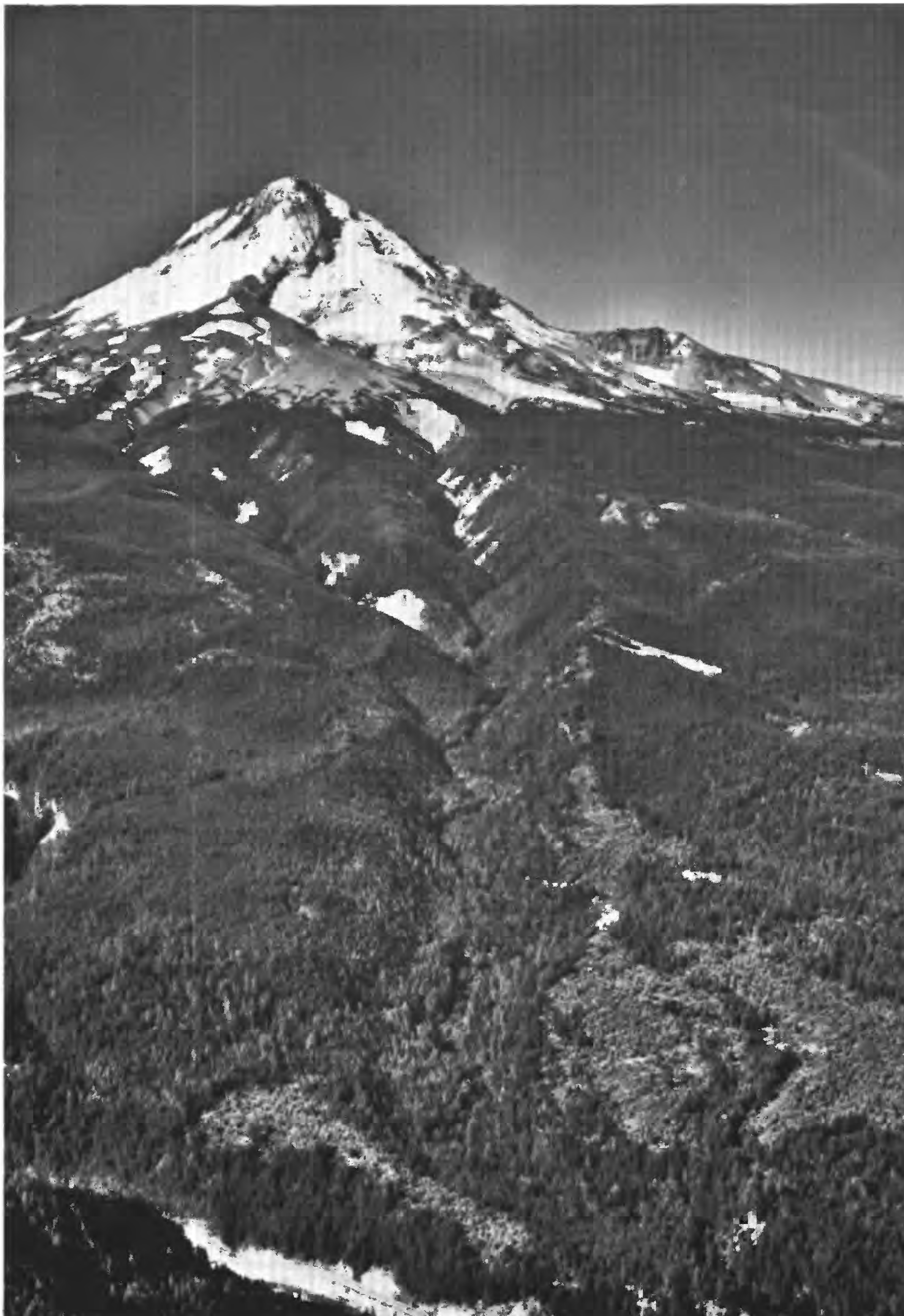
Polallie Creek Debris Flow and Subsequent Dam-Break Flood of 1980, East Fork Hood River Basin, Oregon

United States Geological Survey Water-Supply Paper 2273



Aerial view southwestward up Polallie Creek to Mount Hood. Confluence with the East Fork Hood River visible at lower center. Photograph courtesy of U.S. Forest Service, Mount Hood National Forest, 1971 (L20805-105).

POLALLIE CREEK DEBRIS FLOW AND SUBSEQUENT DAM-BREAK FLOOD OF 1980, EAST FORK HOOD RIVER BASIN, OREGON

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By GARY L. GALLINO and THOMAS C. PIERSON

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CONTENTS

FRONTISPIECE

PLATE
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FIGURES

FIGURES

TABLES

Polallie Creek Debris Flow and Subsequent Dam-Break Flood of 1980, East Fork Hood River Basin, Oregon

By Gary L. Gallino *and* Thomas C. Pierson

Abstract

At approximately 9 p.m. on December 25, 1980, an intense rainstorm and the extremely wet antecedent conditions combined to trigger a landslide of approximately 5,000 yd^3 at the head of Polallie Creek canyon on the northeast flank of Mount Hood, Oregon. The landslide was transformed rapidly into a debris flow, which surged down the channel at velocities of about 40-50 ft/s, eroding and incorporating large volumes of channel fill and uprooted vegetation. When it reached the debris fan at the confluence with the East Fork Hood River, the debris flow deposited approximately 100,000 yd^3 of saturated, poorly sorted debris to a maximum thickness of 35 ft, forming a 750-ft-long temporary dam across the channel. Within approximately 12 minutes, a lake of 85 acre-feet formed behind the blockage, breached the dam, and sent a flood wave down the East Fork Hood River. The combined debris flow and flood resulted in one fatality and over $13 million in damage to a highway, bridges, parks, and a water-supply pipeline.

Application of simple momentum- and energy-balance equations and uniform flow equations resulted in debris-flow peak discharges ranging from 50,000 to 300,000 ft^3/s at different locations in the Polallie Creek canyon. This wide range is attributed to temporary damming at the boulder- and log-rich flow front in narrow, curving reaches of the channel. When the volume of the solid debris was subtracted out, assuming a minimum peak debris-flow discharge of 100,000 ft^3/s at the canyon mouth, a minimum peak-water discharge of 40,000 ft^3/s was obtained.

A computer dam-break model simulated peak flow for the outbreak flood on the East Fork Hood River at about 16,000-30,000 ft^3/s, using various breach shapes and durations of breach between 5 and 15 minutes. A slope-conveyance computation 0.25 mi downstream from the dam gave a peak-water discharge (solids subtracted out) for the debris-laden flood of 12,000-20,000 ft^3/s, depending on the channel roughness coefficient selected.

INTRODUCTION

At approximately 9 p.m. on December 25,1980, a disastrous debris flow burst out of Polallie Creek canyon, Oregon, owing to sustained wet conditions followed by an intense rainstorm. The flow killed the lone camper in Polallie Creek campground, located at the confluence of Polallie Creek and East Fork Hood River, and temporarily dammed the East Fork Hood River (fig. 1). Deposition of this debris mass set the stage for a dam-burst flood that swept down the East Fork Hood River canyon minutes later. Damaged or destroyed were approximately 5 mi of Oregon State Highway 35 (Mount Hood Highway), including three bridges, a water-distribution main line serving the upper Hood River valley, a state park, and a campground. The estimated $13 million in damage caused by this flood prompted the Governor of Oregon to declare parts of Hood River County as disaster areas.

A slope failure in the unconsolidated volcanic deposits at the oversteepened head of Polallie Creek canyon started the chain of events. The landslide was rapidly transformed into a debris flow which surged down the canyon, tearing loose trees, boulders, and easily erodible channel deposits, and incorporating it all into the flow. The magnitude of this rapidly moving debris wave grew steadily as it flowed down Polallie Creek canyon, until it emptied into the East Fork Hood River and formed a temporary dam.

The purpose of this study was to document the Polallie Creek debris flow and subsequent flood, to describe the triggering mechanism and characteristics of the debris flow, and to test and compare some of the analytical tools available to study these events.

Historically, many debris flows in mountain watersheds have been analyzed as water floods, even though the major component of the fluids was solid (Costa and Jarrett, 1981). This fact can result in computed peak discharges and storm runoff amounts that are inaccurate, as this report will show. In this report, comparisons are made between the unadjusted peak flows derived from standard indirect measurement techniques with synthesized peak-water discharges derived from (1) comparisons with ungaged adjacent basins and gaged streams draining Mount Hood, (2) discharges computed from hydraulic formulas, and (3) compositional data on the debris-flow slurry.

GEOGRAPHIC AND HYDROLOGIC SETTING

Polallie Creek lies in a steep, rugged 4.4 mi^2 basin and flows into the East Fork Hood River (pl. 1). It heads at the Cooper Spur summit at 8,514-ft elevation on the east slope of Mount Hood. A deeply incised channel starts abruptly at a headcut at the 6,400-ft level and runs in an easterly course down the flanks of the mountain. The headcut and channel walls (fig. 2) expose beds of unconsolidated and easily erodible volcanic debris, deposited during the Polallie eruptive period 12,000-15,000 years ago (Crandall, 1980). The exposures reveal a succession of unsorted bouldery pyroclastic-flow deposits interbedded with mudflow and debris-flow deposits of generally similar appearance.

Vertical aerial photographs of Polallie Creek taken in 1946, 1959, 1967, 1972, and 1979 show that between the first and last set there appears to have been a 10-20-ft

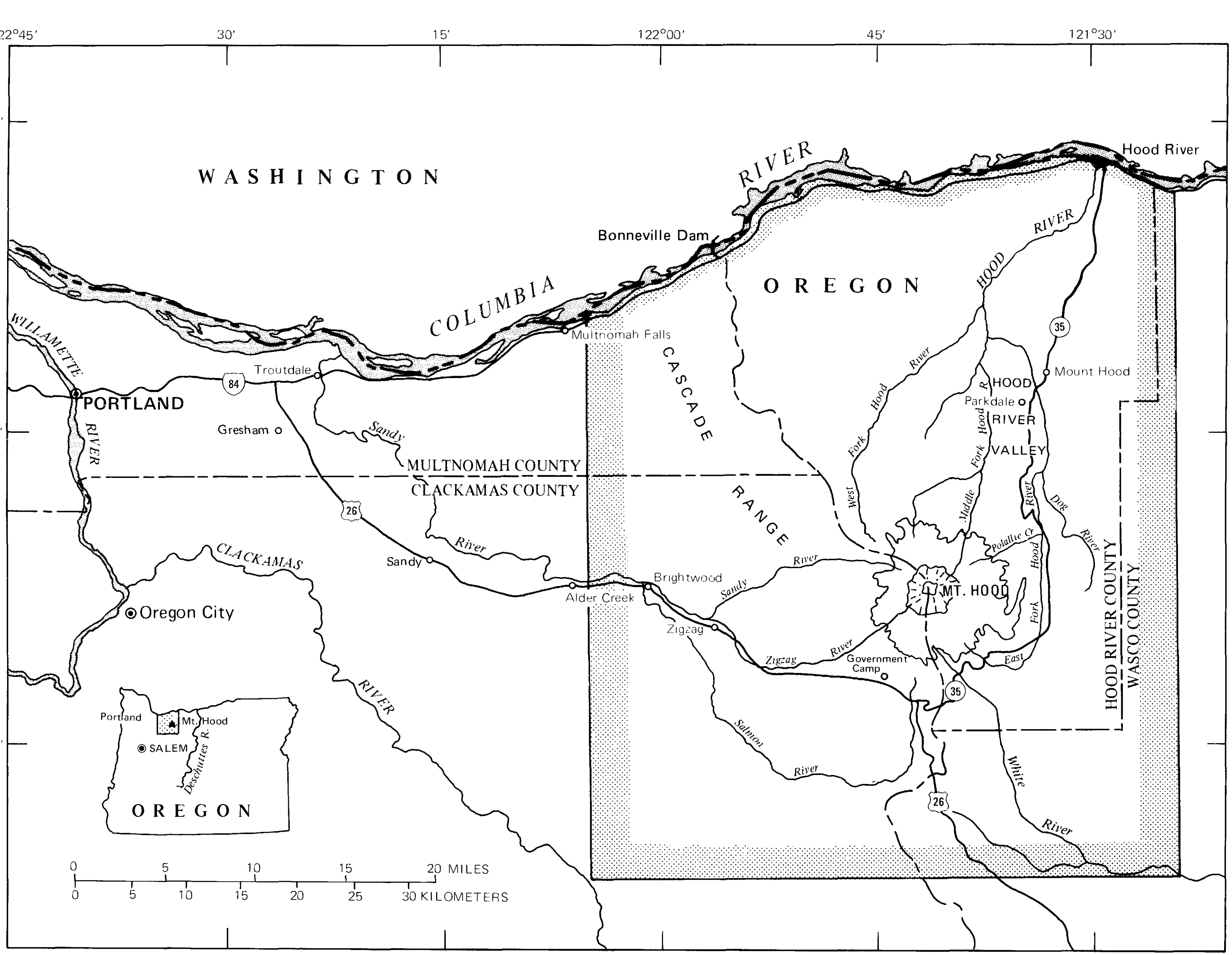

Figure 1. Index map of the Mount Hood area. Study area within shaded boundary line.

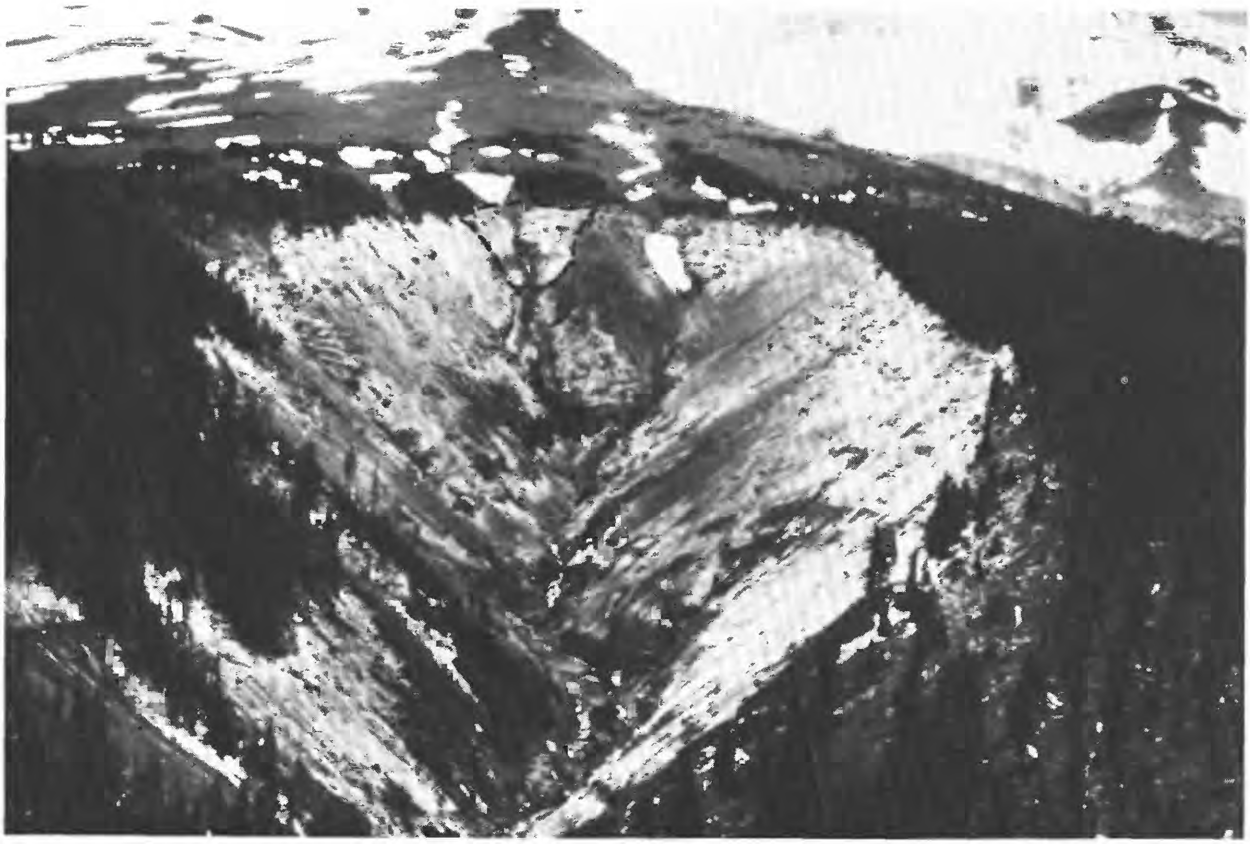

Figure 2. Steep, unstable headcut at head of Polallie Creek canyon. Failure scar outlined by dashed line. Photograph courtesy of U.S. Forest Service, December 26, 1980.

headward extension of the main headcut (approximately the diameter of an average tree crown). The sidewalls of the headcut do not appear to have moved during that interval. The absence of mature forest vegetation in the canyon bottom in each photograph set suggests a periodic susceptibility of this watershed to debris flows. Young, even-aged riparian communities of pioneer tree species, such as alder and willow, are easy to recognize in the photographs and can be good indicators of recent (and datable) channel disturbance by such flows.

Channel slopes in the basin are steep (fig. 3) and provide an efficient flushing system for sediment. The average thalweg slope in the upper 0.5 mi of the channel, between the headcut and the 5,500-ft level, is 1,800 ft/mi (0.34 ft/ft). The average channel slope between 5,500 ft and the confluence with the East Fork Hood River, at the 2,820-ft level, averages about 700 ft/mi (0.13 ft/ft). Slope data were compiled from the U.S. Geological Survey $7^1/_2$-minute 1:24,000-scale Dog River and Mt. Hood North quadrangles.

An unnamed tributary (called "south fork" herein) enters Polallie Creek at about the 3,750-ft level. It has a drainage area of 2.2 mi^2, which is approximately half of the total Polallie basin. This fork was not noticeably affected by the late December storms. The riparian vegetation was not disturbed and there was no evidence of significantly high flows. The geology and average channel slopes of the south fork are similar to those of Polallie Creek above the 3,750-ft elevation.

The upper Polallie Creek channel consists of a series of short, narrow reaches terminating in sharp bends or waterfalls. The base of a major waterfall, approximately 200 ft high, is located at an elevation of about 5,000 ft (fig. 3). The side slopes are steep, poorly vegetated, easily erodible, and show numerous scars from recurring shallow slope failures.

The channel below the confluence with the south fork has somewhat longer, wider reaches terminating in bends that generally have a larger radius than those in the upper reaches. The exception to this generalization is a series of sharp, narrow bends in a bedrock gorge approximately 0.25 mi upstream from the mouth. The side slopes are heavily wooded with conifers and are less steep and more stable than those in the upper basin. The channel area, before the occurrence of the debris flow, was heavily vegetated with small deciduous trees and brush, similar to the south fork. All vegetation was removed from the channel area by the debris flow.

Polallie Creek terminates at a debris fan of unweathered bouldery gravel and sand in the East Fork Hood River Valley. This fan may be correlative with a terrace downstream that is from 16 to 32 ft above river level (Crandall, 1980). Crandall estimated, from tree ring counts, that this terrace was formed during the early

1800's by an "unusual flood event" in Polallie Canyon. This evidence, augmented by the unstable headcut, a deeply incised channel, and preexisting brushy channel vegetation, makes it evident that Polallie creek has experienced floods and (or) debris flows of major magnitude in the past.

Polallie Creek and adjacent streams, Tilly Jane Creek to the north and Cold Spring and Newton Creeks to the south (see pl. 1), have drainage areas of 4-9 mi^2 and have several physiographic similarities. They all have steep channels, particularly in the upper reaches of their basins, that are cut into relatively young, unconsolidated volcaniclastic units, and they have an abundant source of easily erodible material. The lower basins of these adjacent streams are also heavily wooded with conifers and have channels that are bordered by brush and small deciduous trees.

Cold Spring Creek, 1 mi south of Polallie Creek, has a past history of debris flows. A slope-area survey for the peak of December 25, 1980, was run in a reach bordered by the bouldery lateral levees left by a previous debris flow. Tree-ring counts from the largest Douglas fir and larch trees found on these levees place the minimum age of this flow at about 150 years. Cold Spring Creek, which has a predominately easterly flow in its upper basin, is forced by Bluegrass Ridge to flow in a northerly direction for approximately 3 mi. This northerly detour, as compared to Polallie Creek's continuous easterly route, incorporates additional drainage area, decreases the average gradient, and increases the basin response time. Basin-yield estimates for the December 1980 storm were 170 $(ft^3/s)/mi^2$. The narrowness of the East Fork Hood River precludes the formation of a debris fan at the mouth of Cold Spring Creek.

Newton Creek discharges into the East Fork Hood River approximately 6 mi south of Polallie Creek. Of the adjacent streams, Newton Creek most closely resembles Polallie. Their drainage areas are comparable (table 1), and they both run in a generally direct course down the east flank of the mountain. The gradient of Newton Creek is approximately 700 ft/mi (0.13 ft/ft) in the upper basin and flattens to about 250 ft/mi (0.05 ft/ft) in the lower 3 mi of its course. The response time of this basin should be approximately the same as Polallie Creek. Basin yield for the 1980 storm in this drainage was estimated to be 490 $(ft^3/s)/mi^2$.

Tilly Jane Creek drains the adjacent basin north of Polallie Creek. It heads at the 7,000-ft level and drains an area that produces similar base flows, but it did not respond to the December 1980 storm in the same manner as the other adjacent streams (table 1). The basin yield for Tilly Jane was 25 $(ft^3/s)/mi^2$, only about 5 percent of the runoff from Newton Creek and 15 percent of the yield from Cold Spring Creek. A particularly well developed

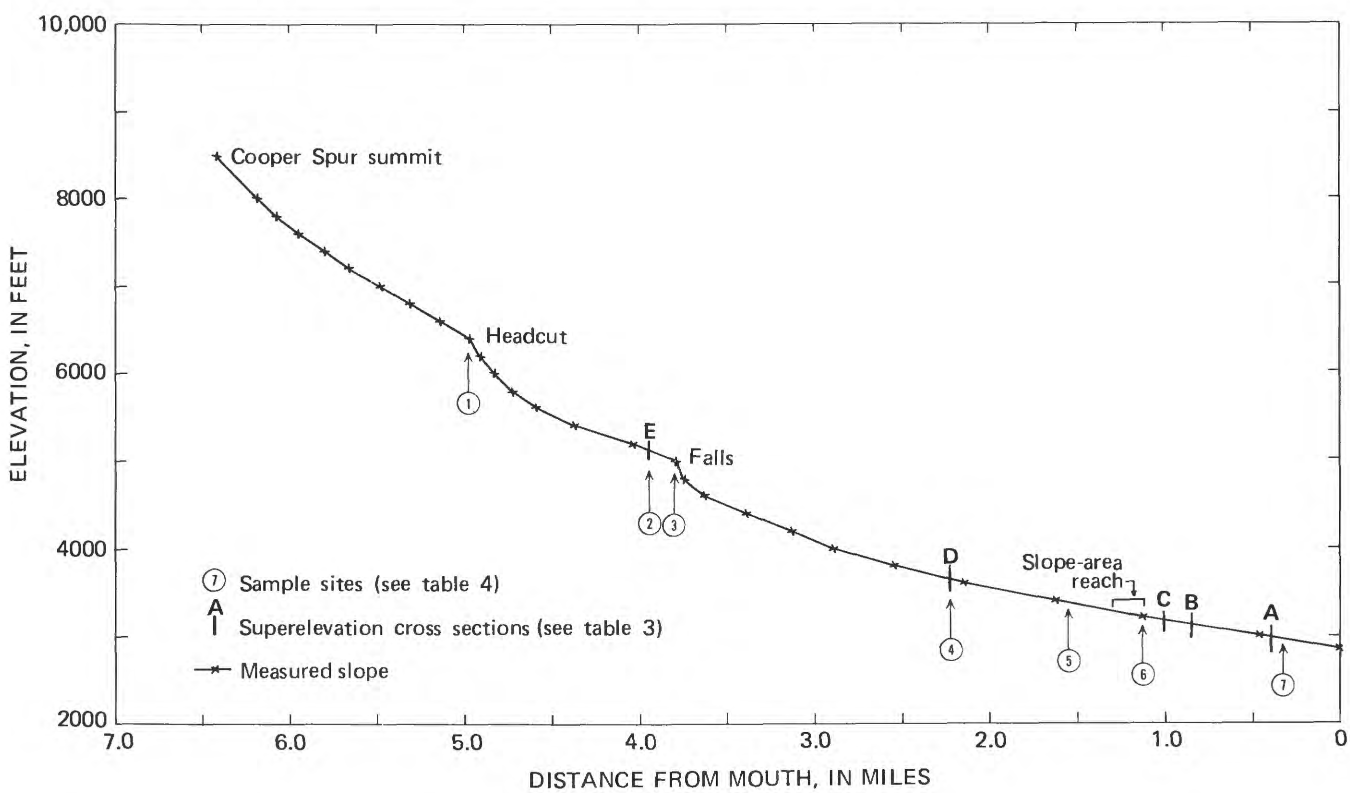

Figure 3. Longitudinal profile graph of Polallie Creek channel. Vertical exaggeration approximately 2.5 times.

debris fan occurs at the mouth of Tilly Jane Creek, suggesting a long history of debris flows in that channel or in adjacent Ash Creek.

THE STORM

Meterological conditions prior to the December 25 flood (fig. 4) were reminiscent of those contributing to other historic floods in the Cascade Range. Maximum temperatures at the Government Camp weather station (elevation 3,980 ft) ranged from 40 to 60 °F during the period December 9-30, which is above normal for that time of the year (U.S. National Oceanic and Atmospheric Administration, 1980). Snowfall in early December was fairly heavy, reaching a maximum of 42 in. on the ground at Government Camp on December 6. The Red Hill

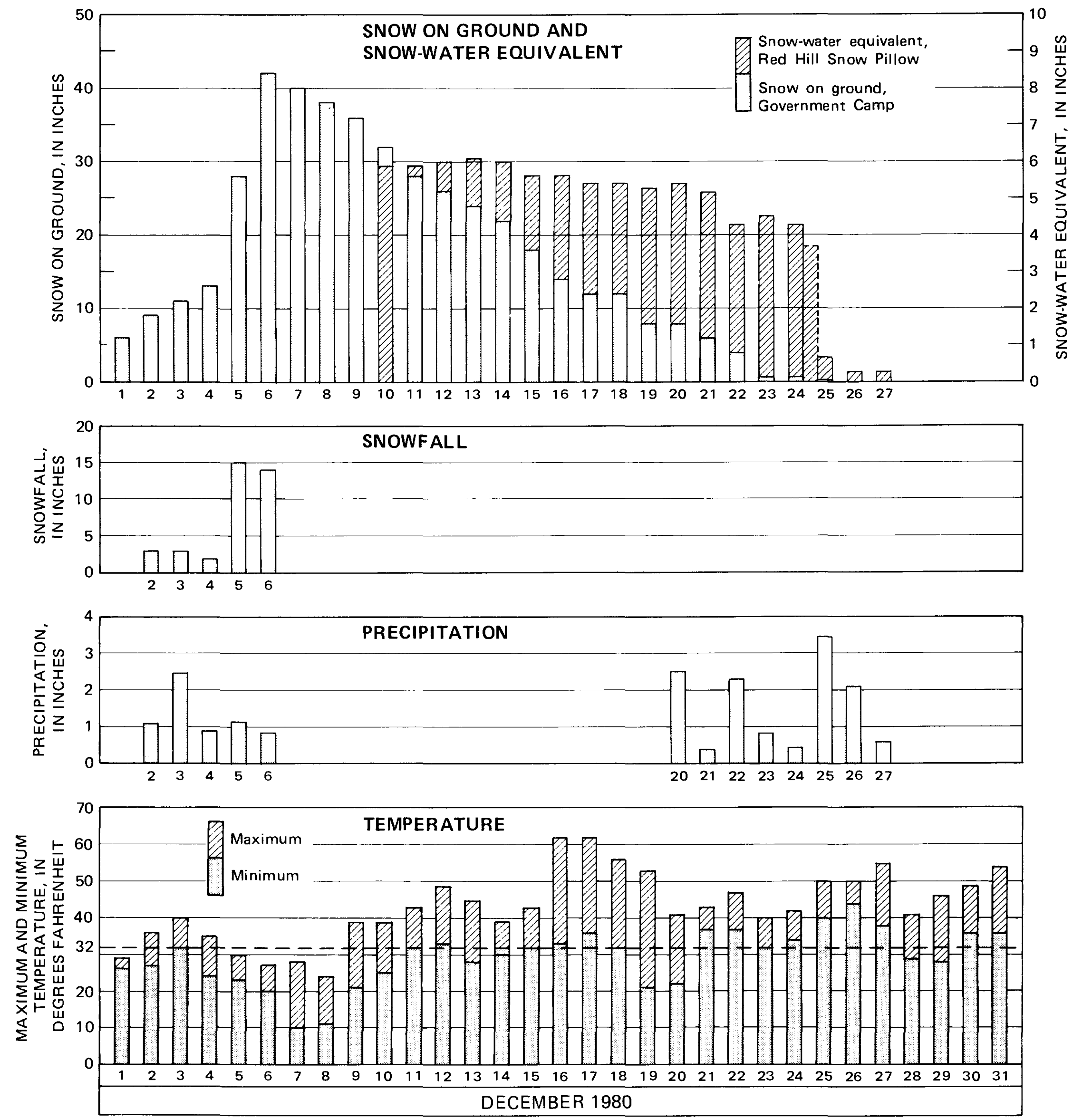

Figure 4. Meteorologic and hydrologic data for December 1980, Government Camp, Oregon.

guard station snow course, located at elevation 4,500 ft on the northern slope of Mount Hood, reported water equivalent of the snowpack to be from 5 to 6 in. from December 10 to 21.

A series of area-wide storms (table 2), combining warm temperatures and heavy rains, started on December 20 and melted the snowpack at Government Camp. At the Mount Hood Meadows ski resort, the snowpack at the 5,200-ft elevation was reduced from 20 in. on December 20 to 8 in. on December 26 (Richard Ragan, U.S. Forest Service, written commun.). The major storm of the series hit on December 25, producing over 3 in. of rain in a 24-hr period (U.S. National Oceanic and Atmospheric Administration, 1980) on already saturated, easily erodible materials denuded of their normal snow cover. The precipitation intensity was 0.1 to 0.3 in./hr for most of the day with over an inch of rain falling in the 4 hr immediately preceding slope failure.

A summary of published observations on the threshold intensity and duration of rainfall required to trigger

Table 1. Flow statistics for selected streams in the Mount Hood area, December 25, 1980

[Bracketed values for Polallie Creek are estimated from the average basin yield of streams with less than 10 mi² drainage area]

Gaging station Number	Gaging station Name	Drainage area (mi²)	Peak-water discharge (ft³/s)	Basin yield [(ft³/s)/mi²]	Approximate recurrence interval (yr)
14120000	Hood River near Tucker Bridge........	279	20,400	73	10
14118500	West Fork Hood River near Dee	95.6	9,680	100	5
14097200	White River near Government Camp	40.7	2,960	73	(1)
	Cold Spring Creek[2]	9.0	1,490	170	—
14138800	Blazed Alder Creek near Rhododendron......................	8.2	1,200	150	2
14134000	Salmon River near Government Camp[3]	8.0	772	97	30
14139700	Cedar Creek near Brightwood	7.9	1,300	160	5
14138870	Fir Creek near Brightwood............	5.5	1,190	220	5
	Tilly Jane Creek[2]	5.4	134	25	—
	Polallie Creek[2]	4.4	[840]	[190]	—
	Newton Creek[2]......................	4.1	2,030	490	—

[1]Period of record not long enough for computation of recurrence interval.

[2]Ungaged stream.

[3]High-elevation gage (3,446 ft); most large storms either occur as snow or as rain falling on thick snowpack and thus abnormally few high flows are recorded.

Table 2. Southern Washington-northern Oregon areal precipitation (in inches), December 18-29, 1980 (National Oceanic and Atmospheric Administration, 1980)

[T = trace]

Station	18	19	20	21	22	23	24	25	26	27	28	29
Cougar 6E (WA)[1]	0	0	0.50	1.90	2.83	1.07	0.64	3.98	3.35	1.06	0.52	0
Bonneville Dam	0	0	.50	1.10	2.95	.49	.58	3.52	2.20	.41	T	0
Hood River Experiment Station ..	0	T	.09	.74	.91	.04	.26	1.88	1.24	.10	T	0
Parkdale ...	0	0	.10	.50	.92	.22	.43	2.11	1.73	.35	T	0
Government Camp ...	0	0	2.68	.36	2.23	.83	.45	3.42	2.08	.60	0	0
Headworks Bull Run	T	0	.84	.79	1.15	.18	1.67	2.09	.88	.78	.03	.19
Marion Forks Hatchery[2]	0	0	.10	.37	2.05	1.00	.56	4.25	2.72	.62	.06	0

[1]Approximately 50 air miles north of Mount Hood.

[2]Approximately 50 air miles south of Mount Hood.

shallow landslides that lead to debris flows (Caine, 1980) suggests that intensities of 0.25 in./hr maintained for 6-7 hours are sufficient to trigger slope failure, given adequate antecedent soil moisture. This threshold appears to have been reached at Polallie Creek on December 25. High seepage pressures at the headcut face, possibly combined with undercutting of the slope by gullying down the face, probably provided the trigger for the main slope failure. Storms of similar magnitude occur almost annually in the Mount Hood area, but only rarely are the antecedent conditions similar to those of December 1980.

THE DEBRIS FLOW

What are Debris Flows?

Water is not the only fluid that flows down channels in steep terrain during heavy rainstorms. Whenever poorly sorted soil and rock debris are mixed with a critical amount of water, usually as a result of slope failure, a dense, structurally coherent slurry forms that is capable of flowing rapidly downhill. Such a slurry can be described as resembling wet concrete. Flows of such mixtures are usually termed "debris flows," although varieties lacking coarse fragments may be called "mudflows" and those occurring directly or indirectly as a result of volcanic activity may also be termed "lahars." To avoid confusion and the implication that events like the Polallie Creek flow occur only on volcanoes, the term "debris flow" will be used in this report.

Debris flows differ from water flows in their basic mechanics and are significantly more destructive. Debris flows contain little water, usually only 10-20 percent by weight. The solid component is a poorly sorted mixture of clay-size to boulder-size particles. The large amount of solids gives the slurries strength and an apparent viscosity much higher than water. The high viscosity dampens turbulence and can allow a debris flow to move more efficiently at high velocities than water (Hughes and Brighton, 1967). The strength factor allows the flows to carry huge boulders (as well as road graders, bridges, and so forth) in suspension (Johnson, 1970; Hamptom, 1979; Pierson, 1981).

Debris flows can occur on various scales. They can be as small as several inches wide and deep, flowing only several inches per second. Bare road embankments during a heavy rain are often good sites to observe such miniature flows. At the other extreme, they can be hundreds of feet wide, tens of feet deep, and flow at many tens of feet per second. Such catastropic debris flows can be triggered by volcanic eruptions (Janda and others, 1981) or massive landslides (Plafker and Ericksen, 1978).

Confirming evidence of a recent debris flow in a watershed is usually easy to find in the field. Diagnostic criteria include: (1) unsorted and unstratified sediment deposits, usually gravelly, muddy sand or muddy, sandy gravel; (2) marginal levees of coarse clasts (usually boulders) and organic debris (tree trunks and branches in forested terrain); (3) terminal steep-fronted lobes of debris bordering the channel or flow path and sometimes found in the depositional zone (channel deposits may be removed by later flood waters); and (4) a high degree of damage, often total destruction, of trees and other vegetation in the flow path on steeper gradients and little damage except burial of trees on flatter gradients. Geomorphic features such as deeply incised channels, steep unstable-appearing headwater areas, and debris fans at confluences with larger streams may suggest a long history of debris-flow occurrence in a watershed.

Polallie Creek Debris Flow

Field observations following the flow event on December 25, 1980, confirmed that a large debris flow and not a water flood had occurred in Polallie Creek. An anomalously large discharge (table 3) from a small watershed was the first indication of a debris flow. Furthermore, (1) the channel had been scoured of essentially all vegetation along the flow path (fig. 5); (2) unsorted and

Figure 5. Debris-flow-impacted channel in lower Polallie Creek 1.2 mi upstream from mouth (slope-area reach). Photograph taken January 7, 1981.

unstratified deposits lined the channel and dried gravelly mud (like dry concrete) coated branches and logs at the flow margin; and (3) marginal levees composed of boulders and logs (fig. 6) had formed in a number of locations. Richard Ragan (U.S. Forest Service) described the massive, unsorted, bouldery deposit at the mouth of Polallie Creek as "resembling wet concrete" on the morning of December 26. The fact that the East Fork Hood River, flowing at an estimated 5,000 ft^3/s at the time, had been temporarily dammed by debris, emphasizes the catastrophic nature of the debris deposition.

The triggering mechanism of the Polallie Creek debris flow was a large slope failure that occurred at the top of the oversteepened channel headcut 4.8 mi upstream from the mouth. It was a relatively thin, wedge-shaped, nearly planar landslide that released at the top of the headcut. Downslope length of the scar was estimated to be 120-150 ft and the width at the top was 150-180 ft, narrowing to a point in the downslope direction. The triangular-shaped mass averaged 6-12 ft in thickness and contained 2,600-7,000 yd^3 of old lahar deposits from the

Figure 6. Lateral levee of coarse rock debris and logs left by debris flow, lower Polallie Creek. Photograph taken April 28, 1981.

Table 3. Channel parameters and computed values for the December 25 debris flow, using the superelevation and slope-area methods

Cross section in down-stream direction (fig. 3)	Distance upstream from mouth (mi)	Average depth at peak flow D (ft)	Channel width at peak flow b (ft)	Superelevation Δh (ft)	Radius of bend curvature r_c (ft)	Channel gradient S (ft/ft)	Mean velocity $\bar{V}$ (ft/s)	Cross sectional area A (ft^2)	Peak discharge Q [$(ft^3/s) \times 10^3$]	Froude number F [$\bar{V}/(gD)^{1/2}$]
Failure scar	4.8									
E	3.9	16.7	177	29.9	443	0.125	49	2,969	145	2.1
D	2.2	10.2	105	3.3	1,827	.078	43	1,087	47	2.4
Slope-area reach	1.2	[1]16.7 [2]11.8	190-240	—	—	.075	25-40	2,500-3,500	94	1.1-1.2
C	.9	22.0	328	50.2	361	.077	42	7,176	301	1.6
B	.8	23.3	144	28.9	433	.060	53	3,324	176	1.9
A	.4	25.3	131	[3]26.2	246	.100	[3]40	[3]3,292	[3]132	[3]1.4

[1]Two upstream sections.
[2]Two downstream sections.
[3]Minimum value, flow overtopped bank.

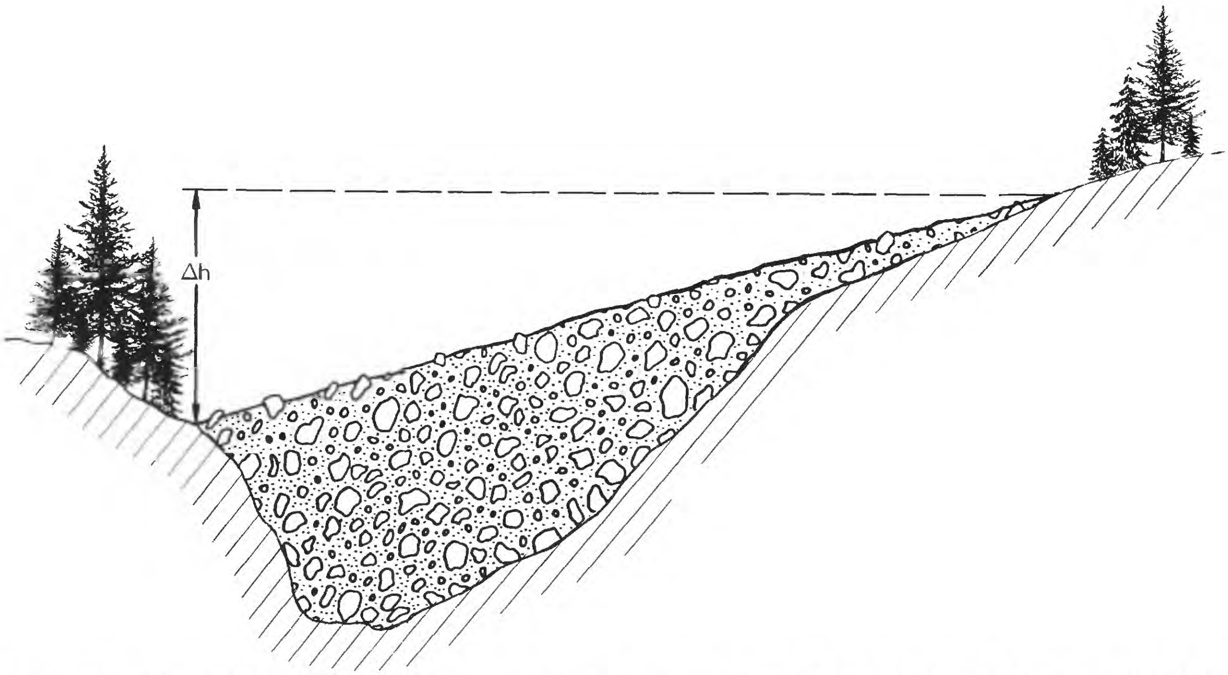

Figure 7. Channel bend in cross section showing superelevation of a debris flow on the outside of the bend.

Polallie Formation. Average slope angle of the failure plane (line from head of scar to toe) was 36°. Although there were no obvious springs or seeps in the scar, the debris mass was probably at or near saturation at the time of failure. The lack of any remnant debris piled at the base of the headcut slope suggests that flowage of the debris began before the landslide reached the channel.

The flow increased in magnitude as it moved down the canyon (1) by bulking (Flaxman, 1974), defined as incorporation of sediment into the flow from erodible channel boundaries; (2) by overtaking and incorporating available streamflow in the channel, and (3) by temporary damming of the flow behind its boulder- and log-rich flow front, particularly in sinuous or narrow channel reaches where frictional resistance to the front was great. This damming and release mechanism probably occurred several times in the narrow upper canyon and at least once in the lower canyon. At the entrance to the narrow gorge 0.25 mi upstream from the mouth, trees were knocked down in an upstream direction, providing evidence of a violent vortex action or a severe backwater condition that caused flow reversal at the edges of the flow. High-water marks in the narrowest cross section in the gorge reach showed the flow to be 40-50 ft deep at the time of the peak.

Flow Velocity and Discharge

Velocities for flowing debris were estimated using two different approaches: (1) momentum- and energy-balance equations—the simplified superelevation formula as described by Chow (1959) and the runup equation[1], and (2) methods utilizing the Manning uniform flow equation—the traditional slope-area and slope-conveyances techniques. Both approaches were originally developed for water flow under assumed steady flow conditions; thus their application to debris flows has been controversial (Costa and Jarrett, 1981). Application of the first approach to a large debris flow that accurred on May 18, 1980, at Mount St. Helens, Washington, resulted in computed velocities that agree with the constraints imposed by known initiation and arrival times of the flow (Pierson, in press). However, computed velocities are minimum values because internal and external resistance to flow is not considered in the equations. A modification to the superelevation formula for dense flows, based on experimental work with sand and water mixtures, has been suggested by Ikeya and Uehara (1982). Their results are not applicable to true debris flows, however, because their model produced grain flows, and the grains settled out of the mixture at bends, allowing flow to ramp up on these deposits.

The superelevation method is based on the principle of tilting of the free surface of open-channel flow in bends, due to the action of centrifugal force (fig. 7). The fluid surface rises on the outside and lowers on the inside of the bend in proportion to the average velocity of the fluid. The difference in elevation is defined as the superelevation, Δh. If it is assumed that all filamental velocities in the bend are equal to the mean velocity, that all stream-

[1]Calculated from the equation $\bar{V} = (2\,gh)^{1/2}$, which is derived by assuming that all kinetic energy of the flow was converted to potential energy in the runup, where $\bar{V}$ = mean velocity, g = acceleration of gravity, and h = height of runup.

lines have the same radius of curvature, and that flow is subcritical, application of Newton's second law of motion to the centrifugal action in the channel bend yields a simple equation for mean velocity (Chow, 1959, p. 448):

$$\bar{V} = \left[\frac{g \Delta h r_c}{b} \right]^{1/2}$$

where

$\bar{V}$ = mean velocity,
g = acceleration of gravity,
Δh = superelevation,
r_c = centerline radius of curvature of the bend,
b = width of the bend.

If flow of Newtonian fluids is supercritical, cross waves should be generated in channel bends and in other localities of irregular channel alignment and shape. In bends, a disturbance pattern from intersecting wave fronts will form and cause multiple maximum and minimum mudline elevations at intervals of Θ degrees on both channel banks, where

$$\Theta = \tan^{-1} \left[\frac{2b}{(2r_c + b) \tan [\sin^{-1} (\sqrt{gD} / \bar{V})]} \right]$$

(Chow, 1959, p. 451). When maximum cross-wave height occurs on the outer bank, it is additive to superelevation and doubles the distance between the mudline and the horizontal water-surface plane; when maximum cross-wave height occurs on the inner bank, it cancels the effect of superelevation, and the resulting mudline coincides with the horizontal water-surface plane (Chow, 1959, p. 450).

It has not been determined whether cross waves develop in the same way for non-Newtonian fluids having internal strength. The measured channel bends in Polallie Creek were long enough to have multiple mudline maxima, but uneven mudlines were not observed. Mudlines on outside banks of bends had smooth profiles with a single maximum point. Therefore, either the flow remained subcritical, despite computed Froude numbers that indicate supercritical flow (table 3), or the flow was supercritical with cross waves migrating because of unsteady flow conditions that left smooth mudlines on both banks. In the latter case, the superelevation equation would still be valid, because the "effective superelevation" measured would be the difference between outside and inside cross-wave maxima, which is the same elevation difference caused by superelevation alone (Chow, 1959).

After velocity was computed by the superelevation equation, peak discharge was obtained by multiplying velocity by cross-sectional area. The results are only approximate, because error is introduced both from the uncertainties and assumptions built into the velocity calculation and from the possibility of changes to cross-

Figure 8. View upstream through the slope-area reach, lower Polallie Creek. Photograph taken April 28, 1981, from bank over-ridden by the debris flow.

sectional area between the time of the debris flow and the time the surveys were made. Channel changes during the period were minor, however, because the debris-flow deposits were still in place over most of the cross section.

Computed debris-flow velocities and discharges are shown in table 3. It appears that the flow accelerated rapidly and maintained mostly supercritical velocities of 40-50 ft/s for almost the entire distance of flow. The relatively wide fluctuations in peak-discharge estimates are beleived to be the result of two opposing mechanisms: (1) normal peak attenuation which, despite bulking and incorporation of water, is generally rapid for large debris flows (Pierson, in press), and (2) temporary damming of the flow by the very coarse flow front in the narrow and sinuous reaches of the channel.

A slope-area survey (Dalrymple and Benson, 1967) was run approximately 1.2 mi upstream from the mouth of Polallie Creek between cross sections B and C (Figs. 3, 5, 8). One of the many problems associated with using the slope-area this technique for debris flows is in the selection of Manning's "n" values. Original field estimates of "n" were approximately 0.040, but were raised to 0.060-0.065 when it was recognized that a debris flow had occurred.[2] The values were raised assuming a higher fric-

[2]"n" values have been computed for three separate debris flows on the North Fork Toutle River (range 0.022-0.051) and one debris flow on Pine Creek (range 0.047-0.147) at Mount St. Helens (Antonius Laenen, written commun., 1984). Discharge values from superelevation computations and postevent channel geometry were used for these computations.

tion factor was necessary to compensate for increased viscosity and internal friction caused by large clasts in the flow. Computations using "n" in the 0.060-0.065 range yielded a peak debris-flow discharge of about 94,000 ft³/s. Three experienced hydrologists were asked to select "n" values from stereoslides of the slope-area reach as a confirmation check of the values used. Their chosen "n" values ranged from 0.040 to 0.065, which yield discharges of 90,000 to 130,000 ft³/s.

The computed peak discharges plot well above a curve developed by Matthai (1969) for values of maximum water discharge versus drainage area in the United States (fig. 9). This fact should alert investigators to an extreme event and the need for further analysis. The Polallie discharges computed using the slope-area method fall between discharges computed using the superelevation technique at sites upstream and downstream from the slope-area reach. The discharges produced by the December 25 storm for all other gaged or surveyed streams draining Mount Hood plotted reasonably close to or below curves developed for maximum peaks in western Oregon (Harris and others, 1979, fig. 9).

The inordinately large discharge coming out of Polallie Creek is due, in part, to the volume of solids in the flow. Assuming 80 percent solids by weight in the flow, which is about 60 percent by volume, a minimum total discharge from Polallie Creek of about 100,000 ft³/s reduces to approximately 40,000 ft³/s for water alone. This clear-water discharge is still very high—above the upper limit of the 1965 basin yield for the United States and also higher than any other stream draining Mount Hood.

Expected Basin Runoff

In order to evaluate the peak discharge obtained by the methods just described, it is necessary to estimate what the runoff from the Polallie Creek watershed might have been. Two methods are available. The first is a regional runoff formula which uses flood-frequency equations developed for the north-central region of eastern Oregon (Harris and Hubbard, 1983). The discharge values for gaged streams with small drainage areas (table 1) indicate an exceedance probability of 0.2 should be used. The appropriate equation is

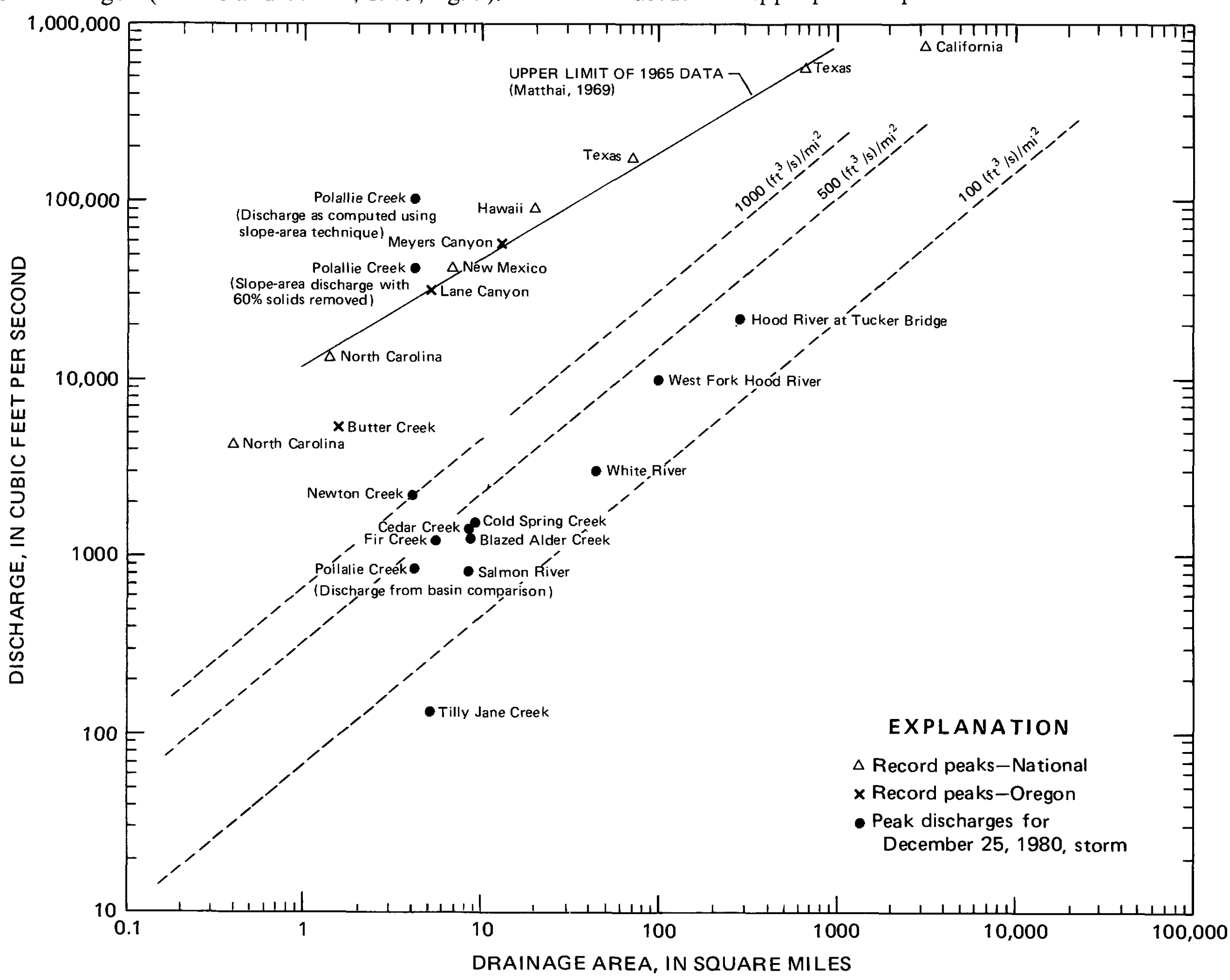

Figure 9. Values for maximum observed peak discharge versus drainage area for Oregon streams in comparison to values for other selected states.

$$Q_{0.2} = 0.00068 A^{0.76} P^{0.90} TI^{2.64}$$

where

$Q_{0.2}$ = A flood with a 20 percent chance of being exceeded in any one year; this is a five-year flood under the "recurrence interval" terminology,

A = drainage area in square miles,

P = mean annual precipitation in inches,

TI = temperature index, the mean minimum January temperature in degrees Fahrenheit, in the basin.

The following values were used for Polallie Creek: A = 4.41 mi^2; P = 100 in. (isopluvial map, Harris and Hubbard, 1983); TI = 28°F (isopluvial map, Harris and Hubbard, 1983). The equation yields a peak water discharge of 800 ft^3/s, which represents a basin yield of about 200 (ft^3/s)/mi^2. A flood with an exceedance probablity of .01 (100-year flood in recurrence interval terminology) computed using the equation developed by Harris and Hubbard (1983) and bulked with solids to 72 percent by volume yields a debris flow with a discharge of less than 6,000 ft^3/s. This discharge is far below estimates made from field measurements and provides additional evidence to the assumption of temporary damming along the flow front.

Another method for estimating expected peak water discharge from Polallie Creek is basin comparison. Peak discharge and basin yield for seven streams with less than 10 mi^2 of drainage area in the Mount Hood area are listed in table 1. The December storms caused moderately high flows with exceedance probablities of less than 0.20 years on most streams in the Mount Hood area. The average basin yield for all of the listed stations in table 1 is 190 (ft^3/s)/mi^2. If this average is used, the peak water discharge for Polallie Creek would have been approximately 840 ft^3/s. This estimated peak agrees well with the peak computed from the regional equation for a flood with a 0.2 exceedance probability. These are reasonable values when compared with curves developed from other historic peak flows in western Oregon, but they are still far below the minimum water discharge of 40,000 ft^3/s estimated for Polallie Creek.

These two estimation methods suggest there was considerably more water in Polallie Creek than can be accounted for from runoff. This is further evidence that temporary damming by the flow front must have occurred. If the channel were blocked for a total of one minute at a sustained peak water discharge of 1,000 ft^3/s, water volume accumulated in the slurry behind the blockage would be 60,000 ft^3. The peak water discharges estimated from the superelevation and slope-area techniques could reflect the outflow from the cumulative total of several small dams, each obstructing flow for several

Table 4. Physical properties of debris-flow slurry samples[1]

[Sample locations are shown on figure 3]

Sample (ordered in downstream direction)	Grain-size distribution (percent)			Mean grain diameter (ϕ units)[2]		Sorting coefficient			Skewness		Percent solids[3]		Fluid bulk density[3] (g/cm^3)
	Gravel	Sand	Silt and clay	M_z	M_ϕ	σ_I (ϕ units)	σ_ϕ (ϕ units)	S_O (mm)	Sk_I	Sk	By weight	By volume	
(1) Material from headcut	9	80	11	1.28	1.24	2.33	2.26	2.78	-0.08	1.07	80	60	2.00
(2) At cross-section E	29	64	7	-.22	-.36	3.12	3.38	5.00	-.11	1.55	82	62	2.03
(3) Head of falls	26	68	6	-.06	-.24	3.04	3.25	4.52	-.17	1.44	81	61	2.01
(4A) At cross-section D	53	44	3	-1.88	-1.67	2.89	3.14	5.04	+.26	.64	84	67	2.10
(4B)	50	45	5	-1.62	-1.43	3.28	3.70	8.32	+.21	.92	84	67	2.10
(5A)	27	62	11	.15	.00	3.16	3.41	5.07	-.08	1.40	86	69	2.14
(5B)	43	49	8	-1.38	-1.63	4.21	4.52	11.28	-.15	2.75	86	70	2.16
(6) At lower end of slope-area reach	26	65	9	-.01	-.18	3.18	3.38	4.74	-.13	1.40	85	68	2.12
(7A) Mouth of Polallie Creek	45	52	3	-1.22	-1.18	3.46	3.94	10.17	+.10	1.47	87	72	2.19
(7B)	69	28	3	-3.60	-2.90	3.77	4.10	6.53	+.67	1.70	86	69	2.15

[1]To allow comparisons with other published values, different methods for computing grain-size parameters are included: M_z, σ_I, Sk_I (Folk and Ward, 1957); M_ϕ, σ_ϕ (Inman, 1952); S_O, Sk (Trask, 1932).

[2]ϕ units = $-\log_2$ (diameter in mm).

[3]Samples reconstituted to estimated original water content.

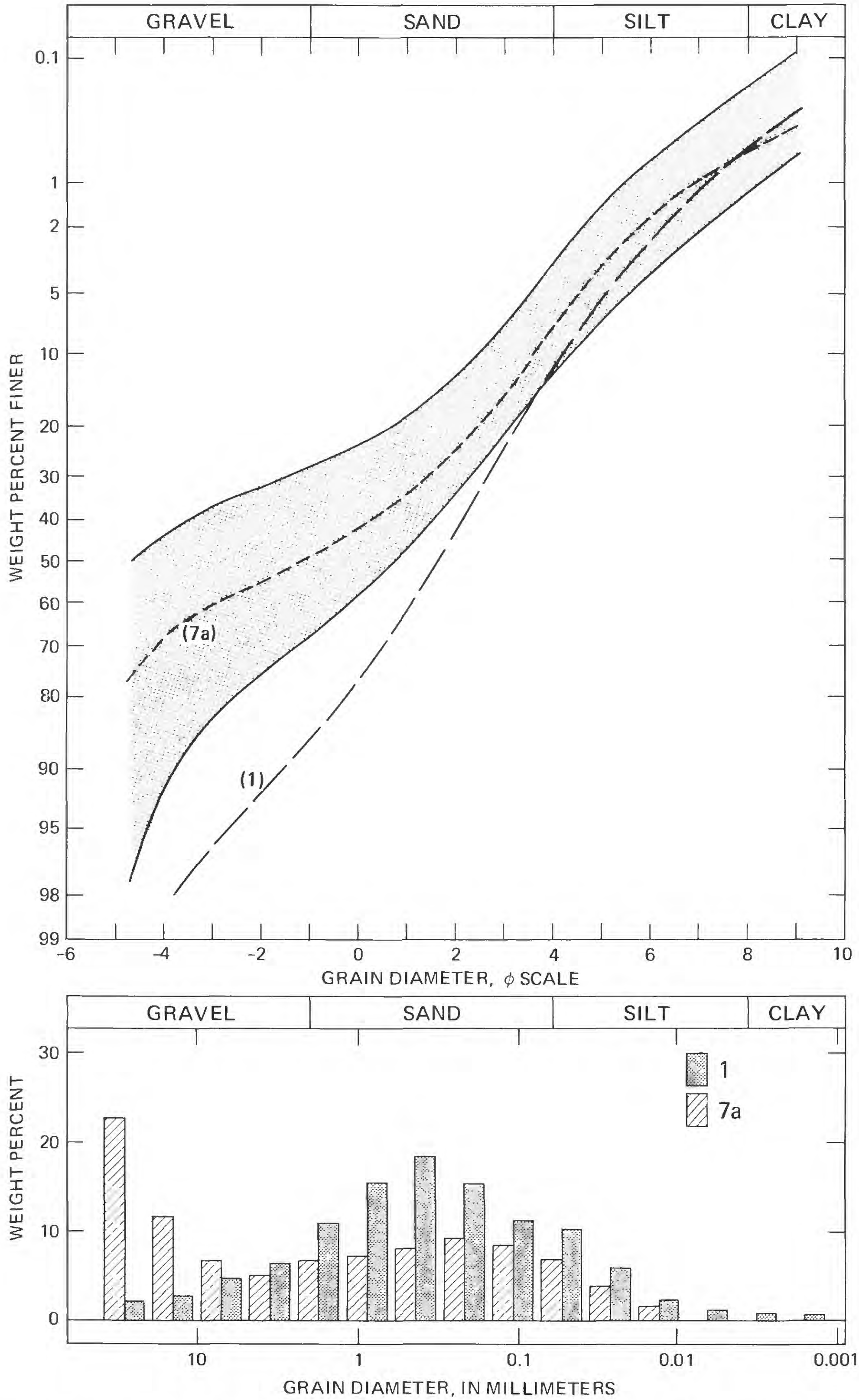

Figure 11. Particle-size distribution of deposits from the Polallie Creek debris flow. Envelope (shaded) of cumulative curves for samples of flow deposits (above). Histogram (below) compares sample of material from headcut (1) with most representative samples of flow deposits (7a) (see table 4).

seconds. This mechanism, combined with bulking and incorporation of water, explains why the Polallie Creek discharge plots so far above the Matthai curve (fig. 9).

Erosion and Deposition

The debris flow severely eroded the Polallie Creek channel, even though a veneer of deposits was left coating the flow path. Channel incision, and incorporation of bed materials and nearly all channel vegetation, began immediately below the failure scar and increased steadily in the downstream direction. By the time the flow arrived at the confluence with the East Fork Hood River 4.8 mi downstream, it had an estimated total debris volume from 90,000 to 130,000 yd^3, a volume approximately 20 times greater than the initiating landslide. Because the erosional capacity of a debris flow is a function of its size (that is, the bigger it gets, the faster it gets bigger), volume increase of the flow should be more exponential than linear with distance downstream, assuming a relatively uniform supply of erodible sediment along the way and a sufficiently high velocity. This suggests that key criteria regulating magnitude of a debris flow are not basin drainage area and storm size, but rather size of the initial failure, length of channel (at steep enough gradients to scour), and amount of erodible sediment in the channel. This event demonstrates that an intially small debris flow can achieve catastrophic proportions over a relatively short distance.

The deposits left behind on banks and terraces in the channel were unstratified, poorly sorted, muddy, sandy gravels and gravelly, muddy sands. Deposition was uneven, and deposits were generally less than 1.5 ft thick (fig. 10). In places the debris-flow deposits were capped by a thin layer of weakly stratified coarse sand, resulting from deposition by the hyperconcentrated recessional phase of the flow (fig. 10A). Size of particles transported ranged from clay to boulders in excess of 3 ft in diameter. Samples were collected at seven locations (including the failure scar, fig. 3) from the head to the mouth of the canyon and analyzed for grain-size distribution. Clasts larger than 4-in. diameter were excluded; therefore, only the flow matrix was sampled.

Results of the analyses are shown in table 4. Samples ranged from 25 to 70 percent gravel (by weight) and contained less than 9 percent silt and less than 2 percent clay. Cumulative grain-size plots (fig. 11) show a relatively narrow envelope of curves with nearly as much variation between replicate samples as between samples from different locations. Statistical grain-size properties are shown in table 4. Although there were no dominant trends in mean grain size or skewness in the downstream direction, sorting appeared to become slightly poorer.

The ratio of water to solids in debris-flow slurries is critical to flow behavior. If too much water is present, the

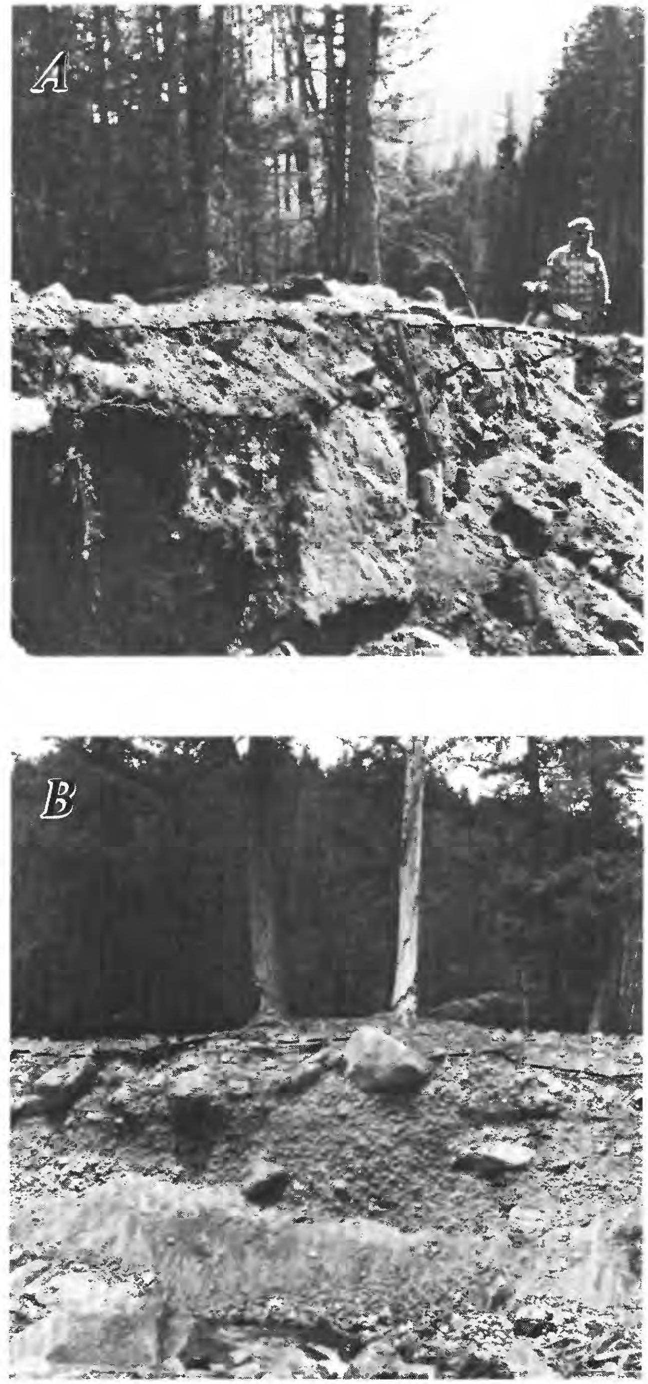

Figure 10. Deposition of December 25,1980, debris flow in Polallie Creek. Photographs taken April 28, 1981. *A*, Veneer (averaging about 1 ft thick) of debris-flow deposit overlying soil developed on older debris-flow sediments. Deposit includes a thin capping of weakly stratified coarse sand. Located 0.5 mi from mouth. Shovel is 30 in. long. *B*, Veneer of debris-flow deposits (less than 6 in. thick) on terrace of older channel fill (also debris-flow deposit). Note severe abrasion to upstream (left) side of tree on left. Located in slope-area reach.

coarse solids separate out and the structural integrity of the slurry is lost, usually resulting in rapid deposition. If too little water is present, cohesion and internal friction impede flowage. The original water content of samples from Polallie Creek was estimated by adding water to samples while mixing, until the consistency of thin, wet concrete was obtained. This method is relatively precise because slurry consistency is extremely sensitive to small changes in water content, but the accuracy may be reduced because some silt and clay may be lost during dewatering of the slurry following deposition. A change of only 4-5 weight percent of water can render a slurry either too dilute or too viscous to flow. Estimated sediment concentrations of the Polallie Creek samples (table 4) were 80-87 percent solids by weight (800,000-870,000 ppm). This translates to a volume concentration of solids from 60 to 72 percent and a fluid bulk density of 2.00-2.19 g/cm^3. Although the trend is irregular, there was an increase in sediment concentration in the downstream direction.

THE DAM-BREAK FLOOD

The sequence of events leading up to the East Fork Hood River flood are shown schematically in figure 12. The debris flow was approximately 50 ft deep and moving at least 40 ft/s when it burst out of the mouth of Polallie Creek canyon. The main thrust of the debris flow was perpendicular to the East Fork Hood River, but some amount of energy was lost as the flow expanded both upstream and downstream. High-water marks on the east wall of the East Fork Hood River define a runup of about 40 ft, which indicates an impact velocity of approximately 50 ft/s. Approximately 90,000-130,000 yd^3 of coarse debris was deposited 7-10 ft thick on the fan at the Polallie-East Fork confluence (fig. 13). As much as 35 ft of material deposited in the East Fork Hood River channel created a debris blockage 750 ft long acting as a temporary dam.

Behind this blockage a water impoundment grew to approximately 85 acre-ft before breaching. The surface area of this impoundment was about 9 acres and the maximum depth was 35 ft. Some of the capacity was taken up by infilling on the upstream side of the blockage by debris. Streamflow in the East Fork Hood River at the time of the blockage was approximately 5,000 ft^3/s, estimated from a slope-conveyance survey 0.5 mi upstream. This inflow, allowing for initial contributions from Polallie Creek, indicates that the East Fork Hood River was blocked for approximately 12 minutes.

The debris blockage was completely saturated when it was emplaced and had very little strength. When the water level behind the blockage rose, exerting lateral pressure, the dam could have failed rapidly through mass failure. It is more probable that the dam breached and failed by a combination of erosion and mass wasting over

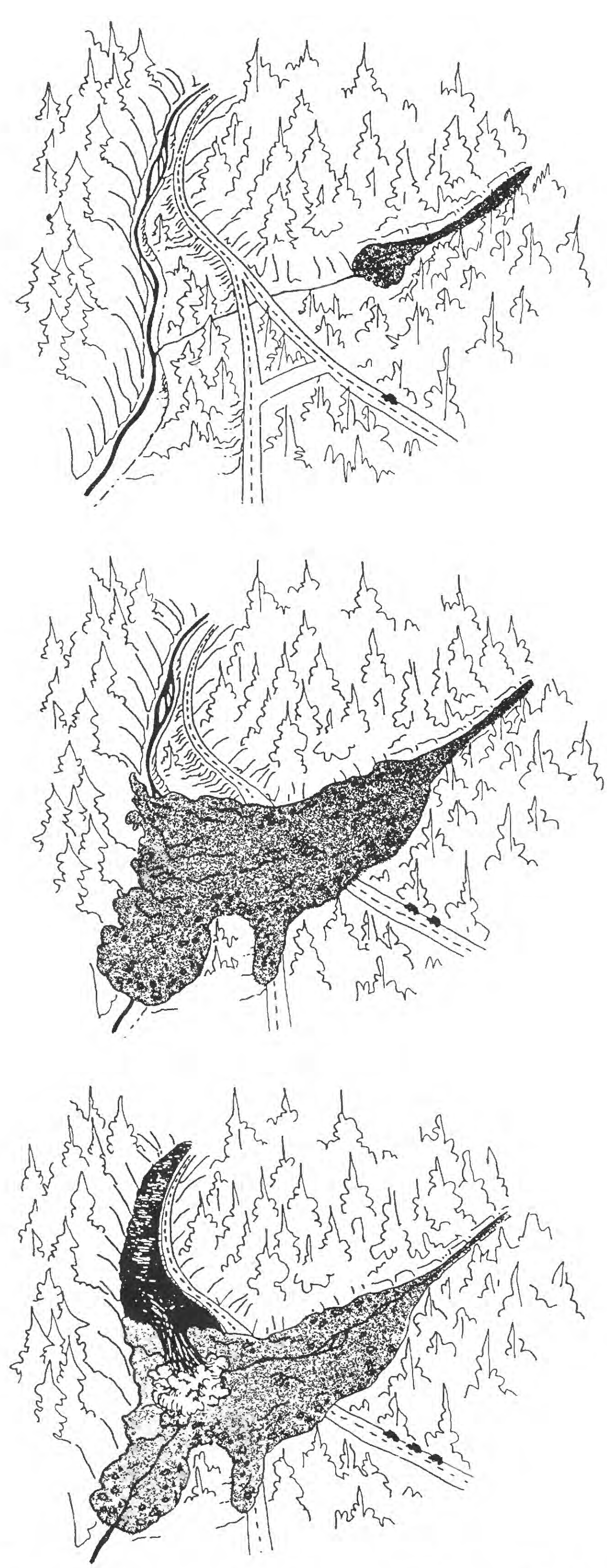

Figure 12. Sequential schematic diagrams showing how the Polallie Creek debris flow caused a flood on the East Fork Hood River. (Drawing by B. Meyers, U.S.G.S., Vancouver, Wash.)

Figure 13. Aerial view of the debris-flow-covered fan at the mouth of Polallie Creek, less than 24 hours after the debris flow had occurred. Outlet channel of the flood through the debris blockage is at the far right center. Photograph courtesy of U.S. Forest Service, December 26, 1980.

Table 5. Model-simulated maximum breach discharges

Case number	Duration of breach development (minutes)	Breach geometry side-slope angle (vertical/horizontal)	Simulated maximum discharge (ft^3/s)
1	3	0.71	37,000
	5		34,500
	15		17,600
	30		12,000
	60		9,200
2	3	.80	32,000
	5		30,000
	15		17,000
	30		12,000
	60		9,200
3	3	1.67	31,000
	5		30,000
	15		16,500
	30		12,000
	60		9,200
4	3	10.0	25,000
	5		24,500
	15		16,000
	30		11,500
	60		9,000

a period of minutes. The peak flood wave 0.25 mi downstream of the breach was a debris flow. Downstream 0.75 mi, it had evolved into a hyperconcentrated water flood, as indicated by the unstratified, moderately well sorted, pebbly, coarse sand making up the peak-flow deposits.

Similar breaches occurred on lakes formed by the eruption of Mount St. Helens. The blockages impounding these lakes were not completely saturated at the time of breaching. Observed times to full breach ranged from a few minutes to 40 minutes in the case of the 250-acre-ft Elk Rock Lake (Jennings and others, 1981). The Elk Rock breach occurred at an erratic rate. If this is a characteristic of blockage failures, it would account for the multiple surges observed on the East Fork Hood River after the breach of the debris dam.

The occurrence of multiple flood peaks on the East Fork Hood River is corroborated by an eyewitness. Randy Iles, an Oregon State Department of Transportation employee, was trapped in his truck by the initial flood wave approximately 1 mi downstream from Polallie Creek. Mr. Iles reported, "As I rounded the corner, I saw about 1-2 ft of water and debris covering the road and behind that a wall of water." The water covering the road is assumed to be from the initial breach of the debris dam on the East Fork Hood River. The bore observed by Mr. Iles is assumed to be from the major breach of the blockage. In a telephone conversation, Mr. Iles reported that the water level, after the initial flood wave, dropped below the level of the road surface but rose one or two more times to cover the road.

A general purpose dam-break model (Land, 1981) was used to estimate peak discharge from the breach. A modification of the same computer model was used to generate a peak-discharge value for the Elk Rock Lake

Figure 14. Flood-deposited boulders strewn on surface of State Highway 35 about 3.5 miles downstream from the mouth of Polallie Creek. Photograph courtesy of U.S. Forest Service, December 26, 1980.

breach. Simulated discsharge for that flood, assuming 6 minutes for the breach to develop, compared well with discharge estimates made by observers. For the breach on the East Fork Hood River, the breach shape was assumed to be trapezoidal. Several side-slope values were tried, ranging from nearly vertical to 1:1.4. The breach was constrained on the right bank by a rock wall with an approximate slope of 1.2:1. In the total breached condition, the left bank had a slope of 0.4:1. It is likely that the breach occurred rapidly once the impoundment filled and overtopped; therefore, the time to total breaching is assumed to be in the range of 5-15 minutes.

Discharges were simulated using several combinations of breach geometry and time (table 5). The simulations indicate that peak-water discharge generated by the breakout of the impoundment was probably from 16,000 to 30,000 ft^3/s. A breach outflow hydrograph was generated by the dam-break model, assuming 15 minutes to full breach, a side-slope gradient of 0.8:1, and an approximate breach time of 9 p.m. Discharge from the breach was also estimated by a slope-conveyance survey at a site approximately 0.25 mi downstream from the mouth of Polallie Creek. The computed total discharge by this method was 30,000-50,000 ft^3/s when using Manning friction coefficients ranging from 0.07 to 0.10. Velocities computed by dividing discharge by cross-sectional area were from 13 to 22 ft/s. Computed values of discharge would be maximums because the cross-sectional area had been increased by subsequent high flows. If outflow at the time of peak discharge was a debris flow as the deposits suggest, actual water discharge would have been considerably less. Assuming 60 percent solids by volume, water discharge

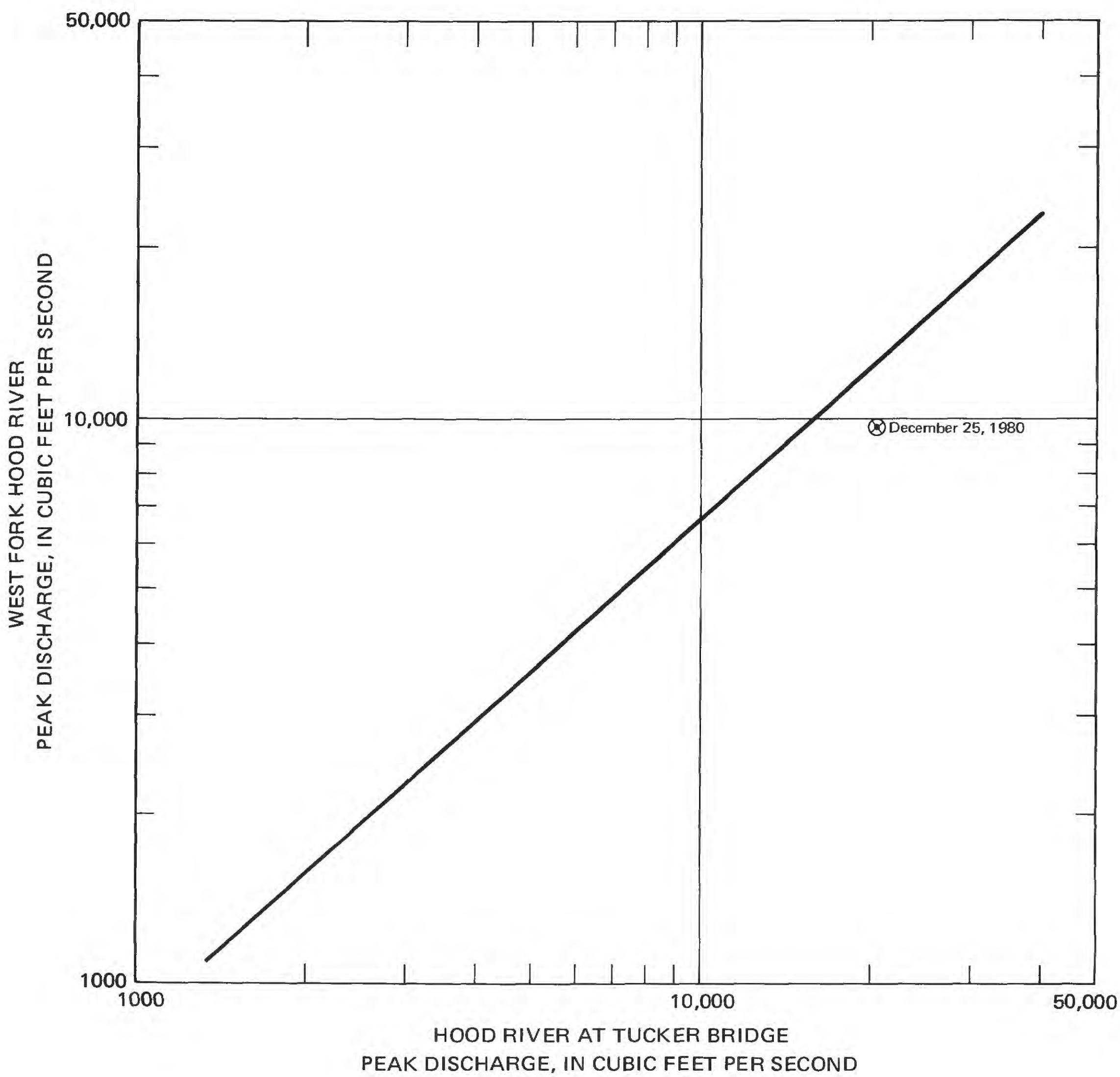

Figure 15. Instantaneous peak discharge correlation, Hood River at Tucker Bridge and West Fork Hood River, water years 1965-81.

was from 12,000 to 20,000 ft^3/s. These values compare favorably with water discharges simulated using the dam-break model.

The flow was erosive enough to dislodge boulders weighing tens of tons from the streambed and deposit them on the highway (fig. 14). The flow attenuated rapidly, creating a flood with a recurrence interval of approximately 10 years at the Hood River at Tucker Bridge near Hood River, Oregon (14120000), gaging station 25 mi downstream. This particular flood compares with a recurrence interval of 2-5 years for most other gaged streams draining Mount Hood. The relation between the annual instantaneous peak flows at the Tucker Bridge gage and the West Fork Hood River gage is plotted in figure 15. This relation indicates the peak discharge at the Tucker Bridge site should have been approximately 15,500 ft^3/s instead of the 20,400 ft^3/s reported for the December 25, 1980, flood, further verifying an abnormal event. The flood destroyed the stage sensor at the Tucker Bridge gage, precluding the development of a complete hydrograph for the flood. The peak stage and corresponding discharge are from high-water marks.

IMPACTS

Debris flows in steep mountain basins, such as the Polallie Creek flow, are violent, catastrophic hydrologic events that cause extensive damage to everything in their path. The flows can be extremely erosive because of high velocities, high fluid density, and massive boulders suspended in the flow matrix or piled up in a steep, grinding flow front. This is evidenced in Polallie Creek canyon by complete removal of forest vegetation in the center of the flowpath and vigorous abrasion of the tree trunks at the flow margin with as much as 25 percent of their diameters removed from the upstream side (fig. 10B).

The most extensive and visible impact of the Polallie Creek debris flow and subsequent flood was the destruction or damage to the highway, bridges, and parks bordering the East Fork Hood River (fig. 16). The Oregon State Highway Division reported the following damage statistics (Coulter and Terpin, 1981): "1.5 miles of highway completely obliterated, another 1.3 miles of roadway at least 50 percent obliterated, and 2.2 miles damaged to where all surfacing must be replaced. Only 1.6 miles of the

Figure 16. Highway and East Fork Hood River channel impacted by the dam-break flood, approximately 1.5 miles downstream from mouth of Polallie Creek. Photograph courtesy of U.S. Forest Service, December 26, 1980.

6.6-mile segment remains relatively intact. Costs to restore the highway to current standards with adequate protection from future floods is estimated to cost $12.1 million."

In addition to the 5 mi of Oregon Highway 35 that were destroyed, the approaches or footings to three bridges were badly damaged. The main supply pipeline of the Crystal Springs Water District, which serves 1,400 residences on the east side of the Hood River valley, had approximately 600 ft of its water main washed away and another 3,500 ft damaged badly enough to require replacement. Costs to repair the pipeline damage were approximately $1 million.

The grimmest reminder of the catastrophic effects of such debris flows is the loss of life. One man was killed by the Polallie debris flow. His trailer was parked in Polallie campground at the confluence with the East Fork Hood River. The trailer was overrun and completely demolished when the debris flow burst out of Pollalie Creek canyon. The old section of Polallie campground was almost completely destroyed (fig. 17), and the new section and Dimmick State Park, 9 mi downstream, were severely damaged by deposits of sand and cobbles left after flood waters receded. Serious consideration should be given to the possibility of debris-flow hazards when locating campgrounds and parks. A debris fan at the mouth of a small stream may be topographically and aesthetically ideal for recreational use, but the hydrologic events that formed it can be deadly.

Failure to recognize that a debris flow has occurred can have additional economic implications. Analyzing debris flows as water floods will yield water discharges that are too large and corresponding computed rainfall amounts that are too high, so that flood-frequency analyses using these data inaccurately predict the frequency of large water floods in small mountainous basins. Using these data for design of engineering structures for retention, diversion, or passing of flood waters can lead to improper designs that waste economic resources.

CONCLUSIONS

A debris flow of major proportion burst out of Polallie Creek canyon at approximately 9 p.m. on December 25, 1980. Debris carried by this flow was deposited in the East Fork Hood River canyon and formed a dam. When the dam breached, a flood wave surged down the East Fork Hood River and caused extensive damage to the highway, bridges, pipelines, and parks that border on or cross the channel.

One of the primary purposes of this study was to

Figure 17. Polallie Campground partially inundated by fine-grained deposits from the recessional phase of the debris flow. Photograph taken December 26, 1980.

compare and evaluate analysis techniques that might be applied to debris flows. The techniques discussed in this report should be applicable to most small, steep mountain basins. The basin-comparison technique, however, is probably not applicable in an area where localized convection storms are common.

The superelevation method appears to give reasonable estimates of velocity and total discharge of the water-debris slurry. The traditional slope-area technique yielded velocity and discharge values that fell within the range of computed discharges using the superelevation technique. The extremely high discharge values computed from these two methods probably reflects temporary damming by the boulder- and log-choked front of the debris flow. Expected basin yield was estimated by comparison with adjacent basins and was two orders of magnitude less than the water discharge computed by the above techniques.

The following analysis techniques are suggested for debris flows: Several slope-area surveys should be run along the channel. Several are needed because the water-surface slope may be flattened upstream from temporary dams or constrictions and oversteepened downstream from such obstructions. Several superelevation surveys should be run in the same general area as the slope-area surveys. Tight bends yield more precise results than wide bends. A complete survey should be made to develop profiles on both the inside and outside of the curve to (1) define maximum superelevation, (2) check for multiple peaks caused by cross waves, (3) map the radius of curvature, and (4) define channel slope. Computational techniques and field data requirements are described in Apmann (1973), Rantz and others (1982), and Chow (1959). Comparison provides a check for gross differences between the techniques.

Slope-area surveys should be run in similar adjacent basins when storms have wide areal coverage. The results of these surveys will provide data for computation of runoff from a clear-water flood and can be used to synthesize precipitation amounts and for flood-frequency analysis.

Discharges computed by slope-area or superelevation techniques should be reduced by the estimated solids content of the slurry. The water content and percent solids of the slurry can be estimated by collecting samples of the unreworked deposit in the vicinity of the survey sites and reconstituting the samples to the consistency of thin, wet concrete. Water discharge values computed using this approach will probably be higher than water floods in adjacent basins because of damming of the debris flow by the flow front.

ACKNOWLEDGMENTS

The authors express their appreciation to Mr. Richard Ragan of the U.S. Forest Service. Mr. Ragan was the first observer with technical background on the scene and provided several photographs as well as eyewitness descriptions of the conditions in Polallie Creek canyon. Special insight to the flood in the East Fork Hood River was provided by Mr. Randy Iles, who will long remember Christmas 1980.

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