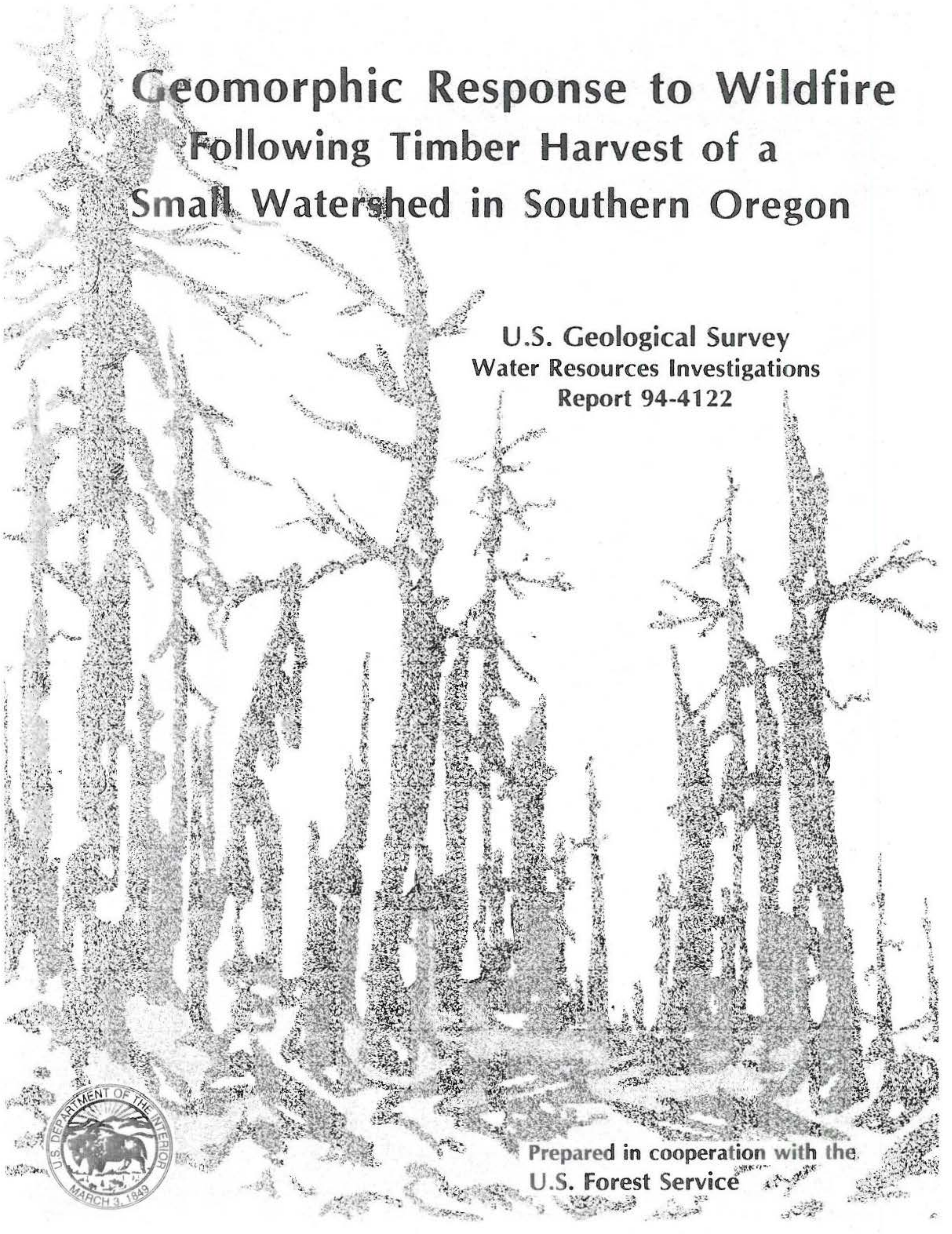
Geomorphic Response to Wildfire Following Timber Harvest of a Small Watershed in Southern Oregon



U.S. Geological Survey
Water Resources Investigations
Report 94-4122

Prepared in cooperation with the
U.S. Forest Service

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By John C. Schmidt

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UNITED STATES DEPARTMENT OF THE INTERIOR

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Conversion Factors and Abbreviations

Multiply	by	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square meter (m^2)	10.76	square foot (ft^2)
cubic meter (m^3)	35.31	cubic foot (ft^3)
kilogram per cubic meter (kg/m^3)	0.00003633	pound per cubic inch (lb / in^3)

Sea level: In this report *sea level* refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) — a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean Sea Level of 1929."

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By John C. Schmidt

Abstract

Negligible geomorphic change occurred in a 1.5-square-kilometer watershed in southern Oregon during the first 2 years following intense wildfire. Parts of this watershed had been partly cut within eight years prior to the fire or had been clear-cut immediately prior to the fire. Precipitation during the two-year study period was about normal (86 percent of normal in the first wet season and 143 percent in second season). There were only minor effects from the wildfire in terms of development of hydrophobic soil conditions, and infiltration rates remained very high in relation to rainfall intensities. Average hillslope lowering rates computed from two erosion plots, reconnaissance measurements of ravel rates, and photograph comparisons are less than 0.001 meters per year, below the detection limits of these measurement techniques. Channel incision rates into gravelly alluvium during the first wet season were less than 0.001 meters per year and may not be related to wildfire occurrence. The negligible geomorphic response to this dramatic destruction of vegetation suggests that the geomorphic role of wildfires in the Pacific Northwest is not necessarily of large scale or magnitude. High infiltration rates, absence of widespread soil hydrophobicity, and low rainfall intensities mitigate erosional tendencies.

INTRODUCTION

Wildfires occur in the western United States in late summer and early fall of most years. One area of interest regarding the effect of wildfire is the degree to which hillslope erosion, debris-flow generation, and sediment delivery are accelerated by this catastrophic destruction of vegetation. Swanson (1981) argued that the geomorphic role of wildfire differs by region, depending on typical fire intensity, frequency, and areal extent and depending on the role played by vegetation in regulating sediment routing. Swanson (1981) also postulated that the geomorphic role of fire is greatest where large, frequent, intense fires affect landscapes in which vegetation typically controls sediment movement.

Relatively little research has been conducted on the geomorphic effects of wildfire in the Pacific Northwest, although parts of the region, including southwest Oregon, have a long history of major wildfires (U.S. Forest Service, 1988). Swanson (1981) estimated that 30 percent of long-term sediment yield in the Pacific Northwest may be related to wildfires. Much research has focused on the chaparral-dominated mountains of southern California. This is a landscape in which fire significantly affects geomorphic processes. Swanson (1981) estimated that more than 70 percent of this region's long-term sediment yield may be related to wildfires. Wells (1987) and Campbell and others (1987) showed that most sediment movement within and away from burned watersheds occurs during the first winter precipitation season after fire. Wells (1987) found that the number of debris flows decreases with time during the first rainy season, and Campbell and others (1987) found that stream channels are re-excavated as the supply of erodible hillslope sediment becomes depleted. Land use may complicate the patterns of wildfire-induced erosion. Megahan (1984) found that the hydrologic effects of fire could not be distinguished from the effects of prior helicopter clear-cutting on steep granitic slopes in Idaho. Helvey (1973) concluded that salvage logging operations (67 percent helicopter and 30 percent tractor) following wildfire did not accelerate fire-induced erosion.

Purpose and Scope

During summer 1987, 3,390 km² (square kilometer) of watershed burned in the western United States, including large parts of northern California and southern Oregon. Regional-scale and large-magnitude hillslope erosion and channel response were anticipated, and the U.S. Forest Service began a program of monitoring erosion on hillslopes in burned areas. The U.S. Geological Survey cooperated in a project designed to document channel changes within and downstream from burned areas and to relate channel changes to hillslope erosion. The project involved measurement and description of the processes that generate and deliver sediment from burned slopes to stream channels and the measurement and description of the extent, range, and timing of downstream channel response. A small, accessible, and intensely burned headwater basin in southern Oregon was chosen for study.

This report summarizes measurements and observations of hillslope erosion and channel response during the first two winter precipitation seasons that followed the 1987 wildfire. Data were collected between October 1987 and September 1989.

Acknowledgments

Holly Martinson, U.S. Geological Survey, helped design and conduct the initial field program. Mikael Jones, U.S. Forest Service, provided much background data, and Gordon Grant and George Lienkaemper of the U.S. Forest Service designed and managed the erosion-pin measurements. Jennifer Gode, Paul Grams, and Douglas Thompson provided field assistance. Reviews of an earlier manuscript by Leslie Reid, Donna Marron, and Gordon Grant resulted in a considerably improved report.

DESCRIPTION OF STUDY BASIN AND PERIOD

Location and General Attributes

The study basin is an unnamed tributary basin in the informally designated Angel Creek watershed, near the headwaters of South Fork Cow Creek in Douglas and Jackson Counties, Oregon (fig. 1). Hillslope erosion and channel change were measured in the drainage basins of North and Middle Forks Angel Creek. This composite basin is called "the study basin" subsequently in this report. Measurements of channel change were also made at other cross-sections within 700 m (meter) downstream from the study basin (fig. 2). Because this study began after the wildfire, pre-fire information on the study area is limited to reconnaissance data on soils and vegetation (Radtke and Edwards, 1976).

Elevation of the study basin ranges between 1,025 and 1,400 m above sea level, and slope angles vary from 10 to 30 degrees. The lowest altitude of cross-sections studied on South Fork Cow Creek are 975 m above sea level. Average annual precipitation at the nearest weather station, Tiller 15 ENE, located about 50 km northeast from the study area, was 1.02 m between 1956 and 1990 (data from Douglas County Water Resources Agency, 1991, Roseburg, precipitation records). Snow accumulates in the basin during winter months, but snowpack data are not available. Natural vegetation in the area consists of mixed fir forest (Douglas fir, white fir, salal, and rhododendron) (U.S. Forest Service, 1987).

Geology, Soils, and Hydrography

The study basin is at the eastern edge of the Klamath Mountains geomorphic province, near the Western Cascades province (Ramp, 1972). Most of the study basin has been mapped as serpentinite of Jurassic age (Smith and others, 1982). The South Fork Cow Creek watershed, upstream from the Angel Creek confluence, is underlain by schist and quartzite (Page and others, 1977).

Parks and Cundy (1988) found that soils of the study basin are typically stony clay loam, and that soil in forested areas is commonly covered with 15 to 75 mm (millimeter) of organic litter. A pre-fire reconnaissance inventory of soils of the Umpqua National Forest designated ridge crests of the study basin as "shallow, colluvial, and residual soils developed over serpentine" (Radtke and Edwards, 1976). These soils typically had surface horizons of gravelly and cobbly fine sandy loam and were "well-drained" (Radtke and Edwards, 1976). Slopes of the study basin mistakenly were mapped as "moderately deep residual soils developed from granitic materials" (Radtke and Edwards, 1976); but there is no granitic bedrock in the study basin. Drainage characteristics of these soils were rated as "excessive," and these slopes should have been rated "well-drained."

North and Middle Fork Angel Creek are second- and third-order channels, respectively, based on the ordering of identified channels and crenulated topographic contours of 1:24,000-scale maps (fig. 1). At the confluence of Angel Creek and South Fork Cow Creek, both channels are

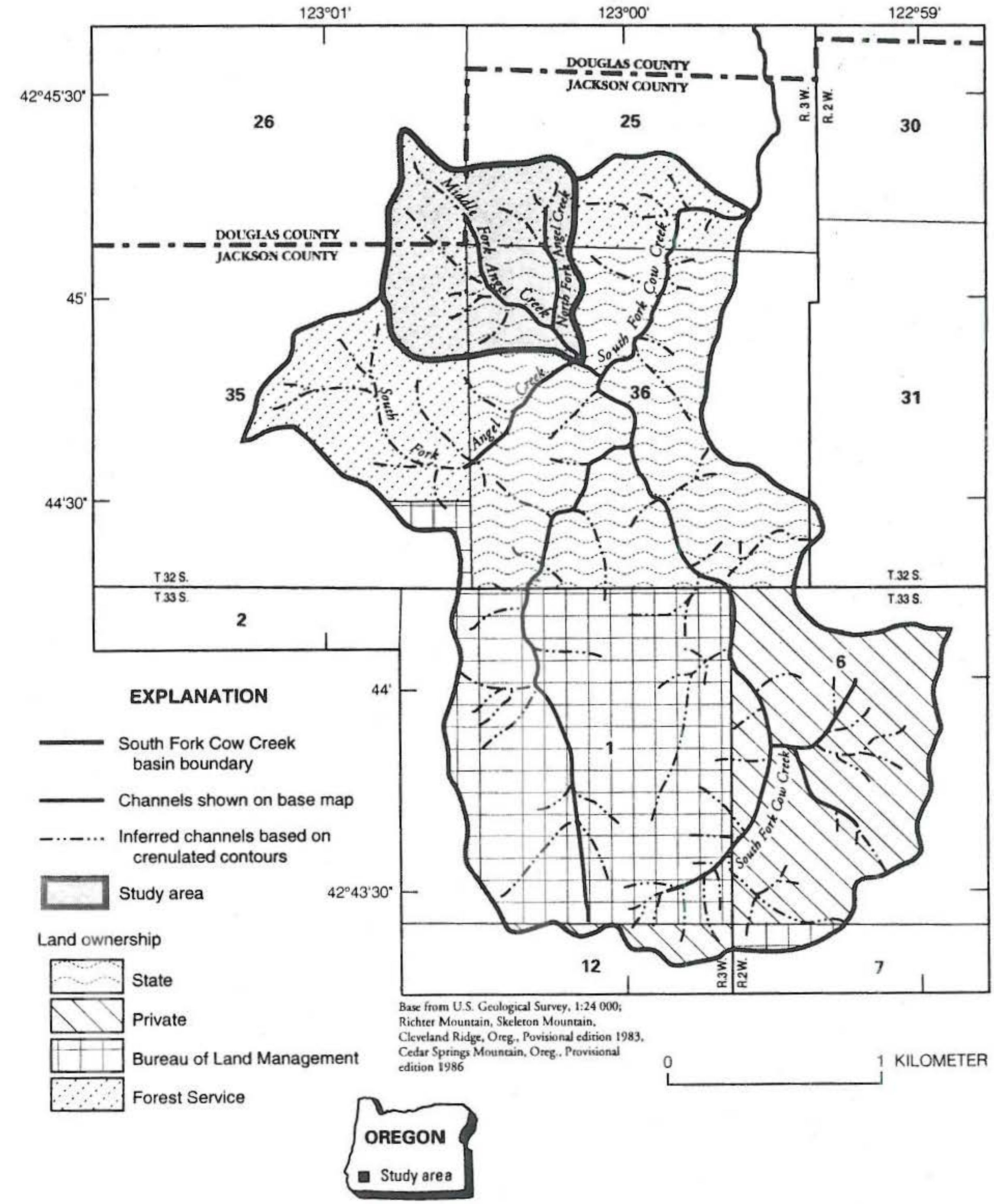

Figure 1. Location of study area, including entire South Fork Cow Creek drainage basin.

fourth order. Channels throughout the Angel Creek basin typically include headcuts 0.30- to 0.60 m in height, especially in third- and lower-order channels. In the upstream direction, discontinuous gullies grade into unchannelized valleys.

In valleys of third- and lower-order channels, there is little sediment storage, and alluvial valley floor widths are less than 7 m, and first- and second-order channels are less than 2-m wide. Sediment storage in channels was estimated based on thickness and area of alluvial deposits on both

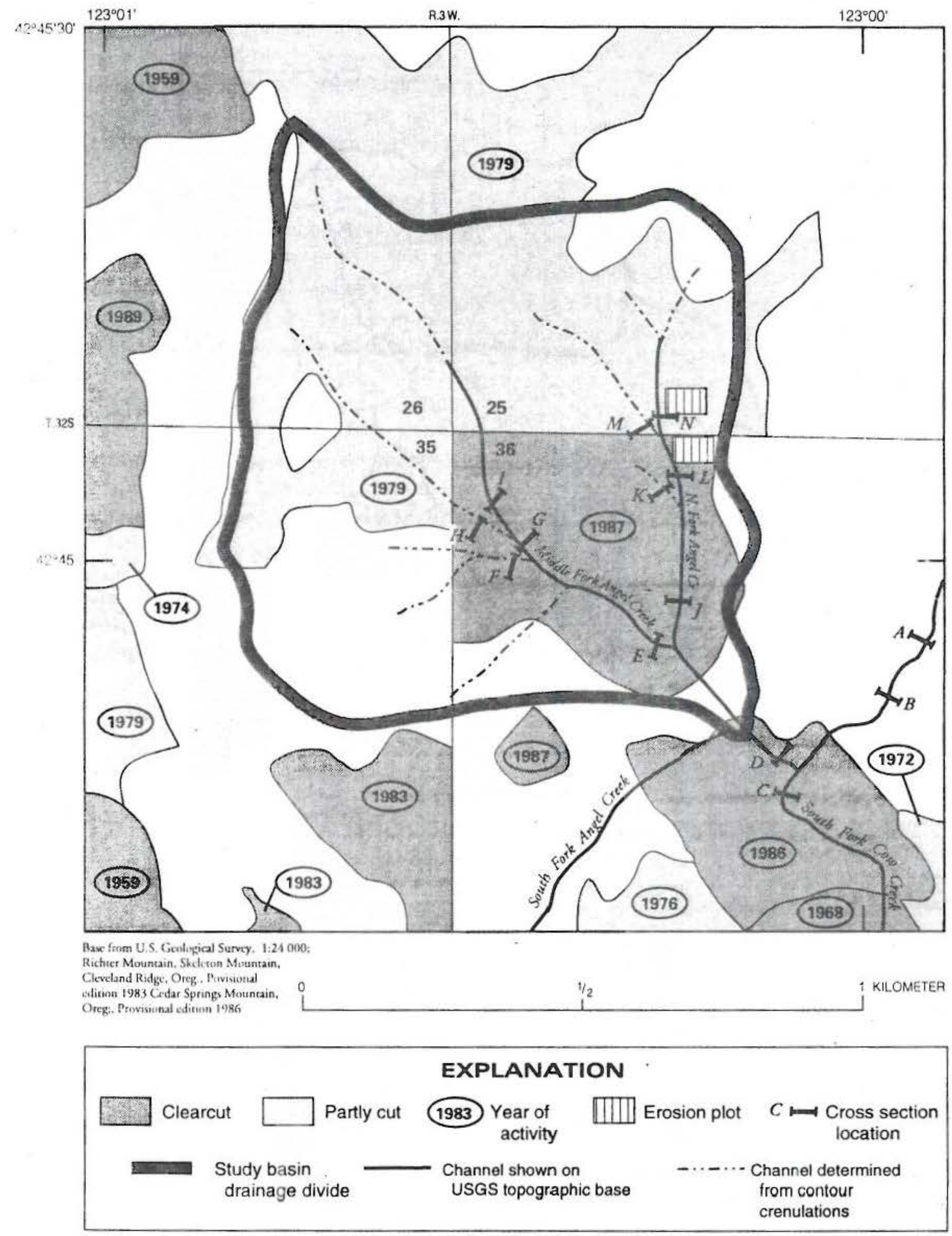

Figure 2. Pre-fire land use.

sides of the channel. Sediment storage along South Fork Cow Creek and at the mouth of Angel Creek is about 5 m^3 (cubic meter) per meter of stream length; this value is about 0.5 m^3/m in first- and second-order valleys.

Land-Use History

The study basin is managed by the U.S. Forest Service and the State of Oregon (fig. 1). Other parts of the South Fork Cow Creek basin are managed by private companies and the U.S. Bureau of Land Management. Most of sections 25, 26, and 35 within the study basin were partly cut using skyline-logging techniques in 1979 (fig. 2), and between 25 and 30 percent of the standing timber was removed. Although no measurements of harvest or post-harvest erosion were made, erosion rates are believed to have been low because of the low percentage of trees removed and the method of removal (W. Conway, U.S. Forest Service Pre-Sale Timber Officer, Tiller, Oreg., 1991, oral commun.). Most of section 36 within the study basin was clear-cut using partial or full-suspension cable-logging techniques during the summer of 1987. Logging crews had left the area only a few days prior to the lightning strikes that caused the wildfire, and slash was still scattered on the ground (C. Dickerson, Oregon Management Unit Forester, Medford, Oreg., 1991, oral commun.). Some skid or tractor trails, such as a tractor-constructed fire break along the western border of section 36, may have accelerated erosion rates. Overall erosion was likely low, however, because of the short period of dry weather between harvest and wildfire. About 50 percent of the remainder of the South Fork Cow Creek basin had been partly- or clear-cut between 1959-1987.

The Angel Fire, as the wildfire was officially designated, began on August 30, 1987, and was controlled on September 9. Preliminary estimates of fire damage were that about 50 percent of the area within the fire line had been intensively burned (fig. 3). The U.S. Forest Service (1987) designated as areas of intensive-burn those where less than 40 percent of the surface was covered by duff and litter after the burn.

Soil Conditions after the Angel Fire

In February 1988, Parks and Cundy (1988) investigated hydraulic properties of the soils in the study basin and found that the effects of wildfire were only minor. Although localized areas of moderate water repellency (using the classification of DeBano, 1981) existed after the fire, soils in a control area of mixed unburned and understory burn were also moderately water repellent. Infiltration rates were very high throughout the study basin and exceeded 1.50 m/hr (meter per hour) (Parks and Cundy, 1988). These values are consistent with the pre-fire designation of these soils as well-drained (Radtke and Edwards, 1976). Considering that the 100-year, 30-minute rainfall intensity for the area is about 0.05 m/hr (Dunne and Leopold, 1978), surface runoff is unlikely, and subsurface flow processes are expected to dominate the hydrologic system. Excavations following infiltration tests showed subsurface flow above a clayey horizon located between 0.03 and 0.09 m below the soil surface (Parks and Cundy, 1988).

Parks and Cundy (1988) speculated that the effects of timber harvest, as well as wildfire, were evident in the characteristics of soils in clear-cut areas prior to the fire. Burned soil in clear-cut areas had a higher saturated water content and was slightly denser (bulk density = 1.03 kg/m^3 [kilogram per cubic meter]) than burned forest soil (0.9 kg/m^3). Burned clear-cut soil also had the highest water retention of any sample, suggesting to Parks and Cundy (1988) the exposure of clayey subsoil by pre-fire erosion. Their suggestion is not supported by characteristics of the soil surface.

Precipitation during Study Period

Precipitation during the first wet season following the wildfire was slightly below normal (86 percent of normal), and somewhat above normal during the second precipitation season (table 1). Total monthly precipitation during November 1988 was the greatest ever recorded at this station for the month. Maximum 24-hr precipitation was typically less than 0.030 m/day during the study period. Only in December 1987, January and November 1988, was this value exceeded. The greatest daily precipitation was 0.234 m on November 30, 1988. Because winter precipitation is due to frontal storms of long duration, the highest daily precipitation values likely occurred over periods of several hours, and it is unlikely that precipitation intensity ever exceeded the infiltration rates of the study basin soils.

STUDY METHODS

General Mapping

Detailed mapping of burn damage intensity in the study basin utilized pre- and post-fire aerial photography, ground observations, and reconnaissance burn-intensity maps (U.S. Forest Service, 1987). Burned areas were assigned one of three ratings: high-intensity complete burn, low-intensity complete burn, or understory burn (fig. 4). High-intensity complete burns were areas of canopy and understory burn. Low-intensity complete burns were areas of canopy and understory burn but where parts of the canopy were still intact. High-intensity burns had lower percentages of duff and litter on the surface although

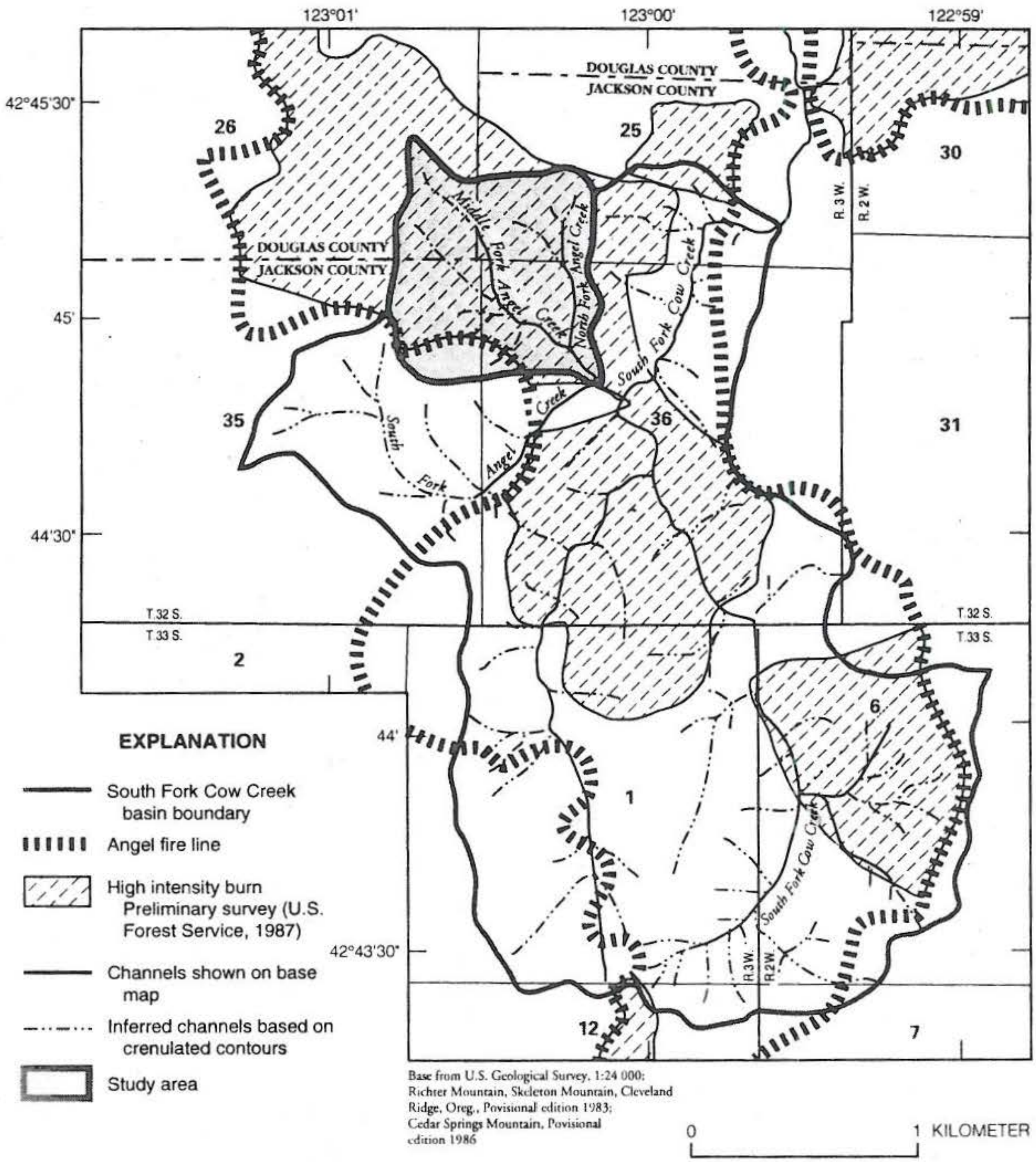

Figure 3. Location of high intensity burn areas and fire lines.

Table 1. Precipitation during the study period at Tiller 15ENE gauge[1]

Year	Year	Monthly total, in meters	Monthly total as percent of monthly average,	Maximum daily total, in meters 1956–1990
1987	October	0	0	0
	November	.117	67	.018
	December	.209	137	.064
1988	January	.130	102	.064
	February	.028	25	.013
	March	.097	88	.015
	April	.109	151	.015
	May	.130	220	.018
	June	.063	185	.018
	July	0	0	0
	August	0	0	0
	September	.033	94	.020
	October	.003	4	.003
	November	.384	219	.234
	December	.104	68	.025
1989	January	.183	143	.056
	February	.081	72	.023
	March	.224	204	.020
	April	.107	149	.030
	May	.069	117	.020
	June	.010	29	.005
	July	.008	80	.005
	August	.048	229	.015
	September	.036	103	.010

[1] Douglas County Water Resources Agency, 1991, written commun.

some areas may have exceeded the 40-percent limit for this burn category established by the U.S. Forest Service (1987). Understory burn areas had intact canopies and higher proportions of duff and litter than other areas.

Hillslope Erosion Plots

Two hillslope erosion plots were established on November 11, 1987. A plot in previously partly cut second-growth forest that had burned at high-intensity was established in the southern part of section 25, and a plot in a clear-cut burned at high intensity was established in the northern part of section 36 (fig. 2). Average hillslope gradient is between 20 and 40 percent and varies with slope position. The arrangement of erosion pins within each plot and measurement procedures were the same as those used in studies at Mount St. Helens (Collins and Dunne, 1986; Swanson and others, 1991). Each plot consisted of 63 pins arranged in three contour transects of 21 pins each; pins were placed about 2 m apart along the contour. Within each plot, transects were spaced at locations about 25, 50, and 75 percent of the distance from ridge crest to valley bottom, and these transects are termed upper-slope, mid-slope, and lower-slope in this report. The pins consisted of welding rods 0.005 m in diameter, each driven between 0.45 and 0.90 m into the ground, the depth depending on soil thickness. Ground-surface elevation was measured with a ruler from the top of each pin to the ground surface. Although measurements were made to the nearest 0.001 m, measurement techniques are only sensitive to changes exceeding 0.005 m. A logging road traversed parts of the crest of the hill above both plots, but there was no indication that this road affected drainage through the plots or caused deposition in them. Erosion plots were remeasured on February 17 and May 31, 1988, and on April 11, 1989.

Site conditions at each pin, such as "open slope" and "upslope from log," were categorized as listed in table 2. Elevation-change data were analyzed by network, by line, by individual site category, and by an aggregated "no influence" category. The latter category included all pins not associated with rills, logs, levees, or vegetation. A two-sample t-test (a = 0.05) was used to determine whether there was a significant difference between values calculated for clear-cut and forest plots. The number and size of rills were also measured.

Table 2. Pin-microsite designations for erosion plots in study area

<u>Pins in the following microsite categories were aggregated as "no influence" sites:</u>

open slope
upslope from log
under log
downslope from log
downslope from burned stump
downslope from charred shrubs
downslope from charred tree
downslope from root
downslope from stump

<u>Pins in the following microsite categories have some extraneous influence :</u>

in rill
in root-throw pit
on log
pin in burned-out stump
pin in fire debris
pin in root
pin in slope indentation
disturbed

Cross-Sections

This report describes changes at 14 monumented channel cross-sections shown on figure 2 and labelled A to N. Locations of the sections with respect to burn condition and intensity may be seen by comparing figures 2 and 4. Initial measurements of cross-sections E to N were made with a hand-level and tape. Other measurements at that time and all subsequent measurements at all cross-sections were made with an engineer's level or theodolite. Surveying errors were calculated on the basis of survey closure and agreement among benchmark elevations of different surveys. Channel changes are reported in terms of changes in thalweg elevation, although complete channel cross-sections were surveyed in all cases. In low-order channels, it was not possible to define the size of the bankfull channel consistently; the resulting uncertainty in comparisons of change in the area of channel cross-sections was large.

Channel slopes were surveyed at most sites in February and June 1988, and September 1989, in order to monitor longitudinal changes in sediment storage. Measured changes in channel slopes were less than errors associated with surveying; a single representative value of slope is reported for each cross-section.

Cross-sections were located near the mouths of channels of different order. Where possible, cross-sections were located in depositional areas where the alluvial valley floor was wider than the channel. These sites were chosen on the basis of the assumption that these areas would be the most susceptible to channel change. Comparison of channel and valley widths in table 3 shows that cross-sections F, G, and K were of channels in wide alluvial areas. In some cases, however, such depositional zones did not exist, and channels in confined reaches were established as monitoring sites. The size of drainage basins upstream from cross-sections ranged in area from 0.02 km^2 to 5.69 km^2 (table 3). Channel slopes ranged between 0.035 and 0.441 m/m, with steeper channels associated with smaller basins. Cross-sections A and B were located downstream from the burned area and were affected indirectly by burning logs that had rolled onto the valley flat.

Other Observations

In order to document hillslope erosion and channel change, 88 replicate photo stations were established at the erosion plots, cross-section sites, and other locations. Photos taken in February 1988 and June 1988, and September 1989, were used to assess how representative the hillslope and channel erosion measurements were and to identify the processes that were active on slopes and in channels. The size distribution of raveled sediment accumulated behind felled logs on hillslopes was determined by visually estimating the proportion of sediment finer than 0.004 m (intermediate axis). The size distribution of bed material in the pools of channels in South Fork Cow Creek was determined with the standard point-counting technique (Wolman, 1954) for

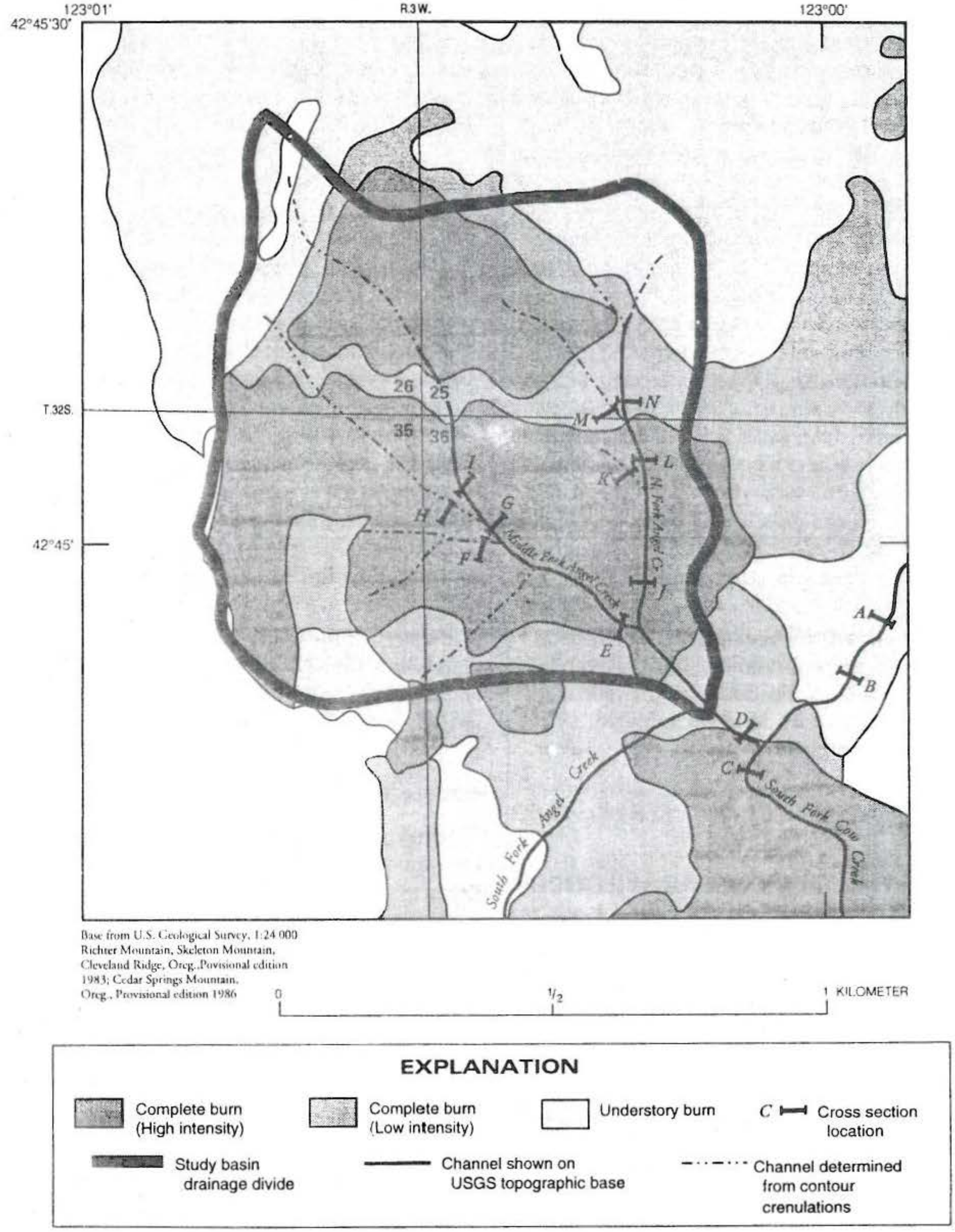

Figure 4. Burn damage conditions at beginning of study.

Table 3. Basin area and channel slope at cross-sections
[km^2 = square kilometer; m/m = meter per meter]

Cross section	Drainage area (km^2)	Channel slope (m/m)	Channel width (m)	Valley width (m)
South Fork Cow Creek				
A	5.69	.035	4.3	7.6
B	5.67	.035	2.4	7.3
C	4.13	.054	3.0	10.7
Angel Creek				
D	1.54	.109	3.8	7.6
Middle Fork Angel Creek				
E	0.47	.167	2.3	6.2
F	0.18	.265	1.7	7.3
G	0.22	.260	0.8	4.3
H	0.10	.336	1.5	1.5
I	0.18	.441	1.8	2.7
North Fork Angel Creek				
J	0.16	.202	1.1	1.7
K	0.02	.328	0.8	3.0
L	0.14	.155	1.2	1.2
M	0.05	.284	1.1	1.1
N	0.07	.152	1.4	1.4

coarse material and by sieving of the fine material. Organics were removed by ignition during laboratory analyses. Laboratory analyses were made at the Cascades Volcano Observatory of the U.S. Geological Survey, Vancouver, Washington.

GEOMORPHIC RESPONSE TO WILDFIRE

Burn Distribution

Comparison of figures 3 and 4 shows that the area of high-intensity complete burn was about 80 percent of the area mapped as high-intensity burn at a reconnaissance level. Thus, the total area of high-intensity complete burn within the boundary of the Angel Fire line was 40 to 60 percent of the total area. The pattern of fire damage within and near the study basin formed a mosaic of different burn intensities with high-intensity burns centered on the clear-cut areas of section 36 and on one partly cut area in the headwaters of the study basin. Most partly cut areas were burned at low intensity, and the headwaters of South Fork Angel Creek were not burned.

Hillslope Erosion

Hillslope erosion processes did not deliver large amounts of sediment to stream channels during the study. In fact, there was no net erosion of either plot during the study. During the study period, average elevation change for all "no influence" pins at the burned clear-cut plot (n = 41) was +0.006 m, compared with +0.002 m at the burned second-growth plot (n = 53). At both plots, most of this increase in elevation occurred between November 1987 and February 1988. Both plots experienced slight erosion between February and May 1988, and variable change during the second season (table 4).

At each plot, the greatest elevation change occurred at the lower-slope transect, and plot averages differ primarily because of differences in elevation increase of the lower-slope transect. Elevation increase along the lower-slope transect at the clear-cut plot was +0.015 m and was +0.005 m in the second-growth.

Average elevation change was small in nearly every category in every transect for each measurement period (table 4) . The only category and site where the magnitude of mean change exceeded 0.010 m was at the mid-slope transect of the second-growth plot (-0.017 m) between February and May 1988.

Although the overall magnitudes of mean elevation change was small, the amount of dispersion in the data sets was variable. The range of elevation change of individual pin measurements is shown by boxplots where the middle 50 percent of the data are included in each box (fig. 5). Figure 5 shows that variability was greatest at lower-slope transects and that at least 50 percent of all pins at each transect had cumulative elevation changes exceeding the measurement errors discussed above. At both plots, all the elevation change of the upper- and mid-slope transects occurred during the first half of the first wet season. Elevation increases continued along lower-slope transects during the second season.

Little rill erosion occurred during the study. No rills developed on the burned clear-cut plot. On the burned forest plot, rills increased in size during the first half of the first winter season but decreased in size thereafter. Rill development did not extend to the lower-slope transect.

Assessment of Erosion-Plot Responses

There are two possible causes for the small net increase in elevation measured at the two hillslope erosion plots: (1) sediment movement across the plots from upslope and (2) change in soil bulk density. Because soil bulk density was not determined at the time of each elevation measurement, there is no way to resolve that uncertainty. Most of the net elevation increase occurred during the first half of the first wet season when each transect in each plot increased in elevation. During that period the lower transects increased more than the upper transects, suggesting that some of the lower transect increase must have been due to sedimentation from overland flow. During the second season, elevation increase occurred only along the lower transects, a pattern likewise indicative of deposition from overland flow.

It is unlikely, however, that the entire area of both plots increased in elevation because of aggradation. Had this occurred, all the erosion supplying sediment to the plots in the first half of the first wet season would have occurred above the plots. Such eroding source areas were not observed. Some change in soil bulk density is therefore likely to have occurred. This likelihood is supported by the positive correlation between plot elevation change and soil bulk density. Although the mechanism of a post-fire soil expansion is unknown, a change in soil bulk density from 1.04 (density of control plot) to 0.9 kg/m^3 would cause an elevation increase of 0.016 m if confined to a 0.1-m-thick soil profile. Thus, a decrease in bulk density of half this amount could have accounted for the entire change in elevation at either plot. The absence of a uniform plot elevation increase after February 1988 makes it unlikely that soil bulk density changes occurred after that date.

The differences in response of the clear-cut and forest erosion plots, although statistically significant, were small. Although Parks and Cundy (1988) had speculated that clayey soil controlled erosion in the pre-fire clear-cut area, the observed response does not conform to that expected with that soil texture.

Observations of Other Hillslope Processes

Raveling of sediment was significant on some hillslopes. Evidence of this process included sediment with incorporated charcoal behind felled, burned logs on hillslopes and cones of raveled sediment at the base of some hillslopes. A wide range of sediment sizes was incorporated in the raveling process. Raveled sediment behind five felled logs near the clear-cut erosion plot was sampled, and 57 percent of the moderately-sorted sediment was finer than 0.004 m. Median size of the gravel fraction was about 0.030 m. By dividing the volume of sediment accumulated behind four of these logs by the contributing hillslope areas, an erosion rate of 0.001 m/yr was estimated for the first winter season. These few observations are insufficient to estimate a basin-

Table 4. Mean elevation change of indicated microsite category at erosion plots

Plot and Line	Elevation change, in meters, during indicated period			
	November 1987– April 1989	November 1987– February 1988	February 1988– May 1988	May 1988– April 1989
		CLEAR-CUT PLOT		
Entire plot				
open slope[1]	+.006[2]	+.007[2]	02	-.001[2]
no influence[1]	+.006[2]	+.007[2]	-.002[2]	+.001
all pins[1]	+.004[2,3]	+.005[2]	-.003[2]	+.001[2]
Upper slope transect				
open slope	0	+.005[2]	02	-.003[2]
no influence	0	+.006[2]	-.001[2]	-.002[2]
all pins	02	+.003[2]	-.002[2]	-.001[2]
Mid-slope transect				
open slope	0	+.007	02	-.006
no influence	+.002	+.006[2]	-.002	-.002
all pins	0	+.005[2]	-.003	-.001
Lower slope transect				
open slope	+.019[2]	+.009	0	+.005
no influence	+.015[2]	+.008[2]	-.003[2]	+.006
all pins	+.010[2]	+.006[2]	-.003[2]	+.006[2]
		SECOND-GROWTH PLOT		
Entire plot				
open slope	02	+.008[2]	-.007[2]	02
no influence	+.002[2]	+.008[2]	02	0
all pins	+.003[2]	+.008[2]	+.006[2]	02
Upper-slope transect				
open slope	+.002	+.007[2]	-.002[2]	+.002[2]
no influence	+.001	+.007[2]	+.001[2]	+.001[2]
all pins	+.001[2]	+.007[2]	02	+.001[2]
Mid-slope transect				
open slope	0	+.007	-.017[2]	0
no influence	0	+.008[2]	0	0
all pins	0	+.008[2]	0	0
Lower slope transect				
open slope	+.006[2]	+.009	0	+.006
no influence	+.005[2]	+.010[2]	02	+.005
all pins	+.004[2]	+.009[2]	02	+.004[2]

[1] See table 2 for explanation

[2] Clear-cut and forest values statistically different (two sample t-test; $a = 0.05$; $H_o : \text{mean}_{\text{clear-cut}} = \text{mean}_{\text{forest}}$)

[3] The value for the entire study period for a category does not always equal the sum of the study period increments because some periods differ in the number of pins in those categories

wide rate of sediment raveling, but they document the occurrence of the process.

On some hillslopes in clear-cut areas, tree-throws initiated the downslope movement of soil. One such downed tree occurred per 270 m^2. Root wads of each tree held an average of 0.3 m^3 of soil. Some snags or standing trees had been left in the clear-cut (C. Dickerson, Oregon Management Unit Forester, Medford, Oreg., 1991, oral commun.) and most fell during the fire. The proportion of tree throw related to wildfire or timber harvest was not determined;, the occurrence of some unburned exposed roots in severely burned areas, however, confirms that some tree throw occurred during or after the fire.

Soil movement associated with piping was not observed during the first wet season, although the opportunity for piping existed. Burned-out root holes were irregularly distributed; some areas had no holes, while other areas had an average of 1 per 200 m^2.

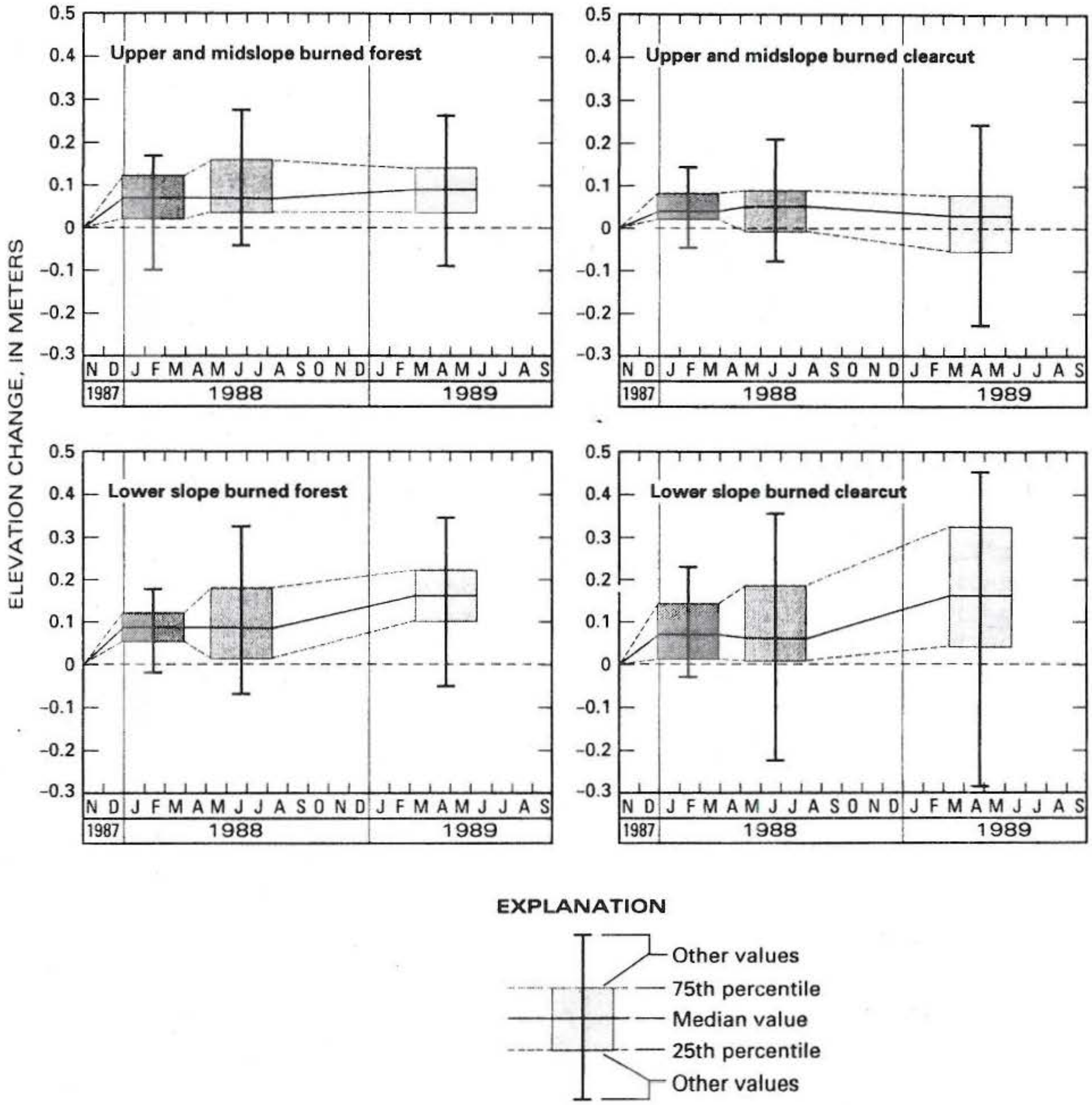

Figure 5. Elevation change at erosion plots and range in values of pins in "no influence" category.

Channel Changes

At all channel cross-sections the change in thalweg elevation was less than 0.3 m (fig. 6). At half of all cross-sections the change was less than 0.1 m. The response of low-order channels was not consistent, with initial fill at some sites followed by erosion, while at other sites erosion preceded fill. At each fourth-order cross-section (sections A, B, C, and D), channels filled during the first half of the first winter season; however, there are insufficient data to determine if this pattern reflects system-wide behavior of the higher-order channels.

At most sites, the trend in elevation change during the first precipitation season reversed during the second season. The only exception to this pattern was at cross-section A which aggraded throughout the study period. No relation was found between the magnitude of elevation change and stream order, channel slope, or percentage of burned drainage basin.

Other Observations of Channel Response

Repeated photography and mapping of channels indicated that some headcuts in low-order channels migrated upstream (typically less than 0.3 m) during the study period, eroding the bed material of channels in the valley fills. Many of these headcuts developed where debris comprising log jams had burned sufficiently to expose previously deposited sediment. In one case, a headcut 1.5 m in height retreated upstream 0.3 m during the first wet season, suggesting that destabilized or burned-out log jams have the potential to generate knickpoint migration within these drainages.

A few cones of ravelled gravel accumulated on valley floors, demonstrating that some hillslope sediment was delivered to stream channels. However, the total volume of such material was small.

On South Fork Cow Creek between cross-sections A and B, organic debris and fine sediment aggraded in some pools during the study. The magnitude of such aggradation is shown in the thalweg elevation change at cross-section A (fig. 6), and the changes in size distribution are illustrated in figure 7. At the end of the first wet season, organics and fine sediment mixed with charcoal and burned debris comprised between 10 and 20 percent of the total sediment stored in the reach at the beginning of the study. About 25 percent of this accumulated sediment was organic material.

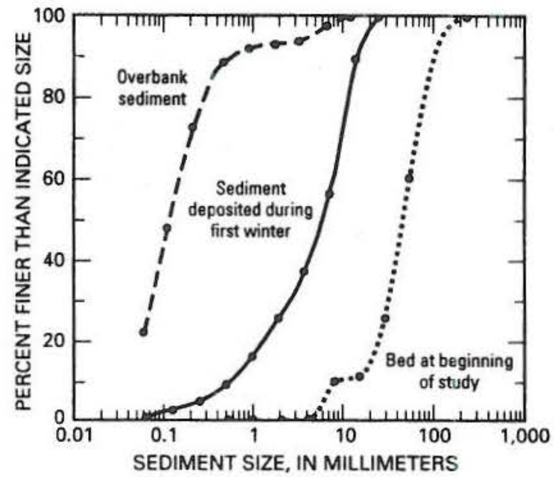

Figure 7. Cumulative size distribution of bed and overbank material, cross-section A.

DISCUSSION AND CONCLUSIONS

Landscape response was minor during the two wet seasons following wildfire. Net change in elevation of hillslope erosion plots was positive, a trend unlikely to be sustained over a much longer term. Nevertheless, assuming that the plot data document a general lack of erosional response to the wildfire, it is clear that sediment volumes delivered to stream channels were not unusually high during the first two years of the watershed response. Reconnaissance measurements of hillslope ravel rates suggest an order-of-magnitude erosion rate by that process of 0.001 m/yr, but the areal distribution of this process is unknown. The few observations of ravel cones at the bases of slopes also indicate that much hillslope-derived sediment did not reach stream channels during the study period.

Stream channel response during the two-year post-fire study period is difficult to categorize because of its variability. The average rate of vertical channel erosion was 0.03 m^3/m of channel length for low-order channels during the first wet season. That volume corresponds to an approximate total volume of 90 m^3 of sediment

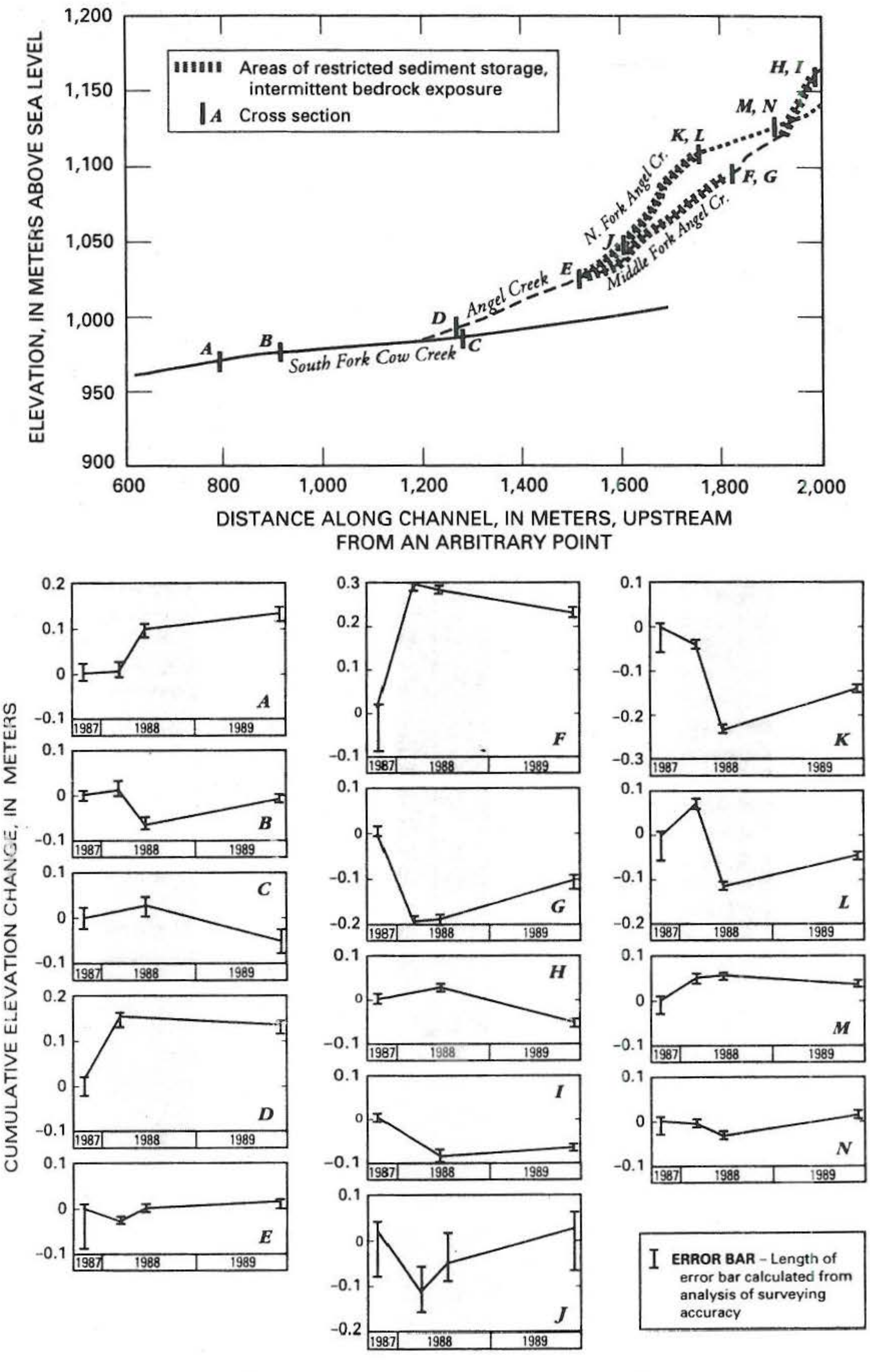

Figure 6. Longitudinal profile of study reaches and thalweg-elevation change at cross sections.

for all the streams in the study basin, which in turn corresponds to a vertical degradation rate of 0.0001 m for the watershed during the first wet season. The low values and the short period of post-fire study prevent a clear correlation of the measured change with wildfire disturbance. Nevertheless, the documented absence of dramatically increased sediment yields following wildfire is in itself an important conclusion.

The measured amounts of landscape response are very low, and the errors associated with their measurement are large. Rates measured in the two-year post-fire period are not clearly different from estimated long-term rates, despite the expectation of much higher rates of change. Reneau and Dietrich (1991) estimated that the long-term erosion rate for mountainous areas west from the study area is about 0.0001 m/yr during the last 4,000 to 15,000 years. These rates contrast with measured rates at eruption-affected volcanoes of 0.025 to 0.100 m/yr (Swanson and others, 1991).

The first two years after the Angel Fire were not a period of accelerated erosion, and the anticipated large-scale watershed effects did not occur. Hillslope erosion measurements at Long Gulch, also in southern Oregon (F.J. Swanson, U.S. Forest Service, Corvallis, Oreg., 1991, written commun.) are consistent with the data reported here. Major wildfires in this region do not necessarily lead to accelerated erosion; the high soil infiltration rates, absence of hydrophobic soils, and low rainfall intensities are such that the commonly assumed role of wildfires in accelerating erosion may be overstated.

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