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Land Use, Floods, and Channel Changes: Upper Middle Fork Willamette River, Oregon (1936–1980)

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Flow trends and channel characteristics from 1936 to 1980 were evaluated for the Middle Fork Willamette River, which drains a 668-km^2 forested watershed in the Cascade Mountains of western Oregon. An inventory of aerial photographs from 1959 to 1972 shows that landslides associated with roads and in clearcuts were 27 and 23 times more frequent, respectively, than in forested areas. Numerous landslides unloaded sediments directly into the drainage system; most landslides appear to have been initiated during a large flood (return period greater than or equal to 100 years) of December 22, 1964. Analysis of precipitation and peak flows (greater than 100 m^3 s^{-1}) from 1958 to 1980 by means of power function models suggests a trend of increasing flows as timber harvesting and road building expanded in the basin. Changes in channel pattern, documented from aerial photographs, show major increases in channel width from 1959 to 1967 and a trend of decreasing width from 1967 to 1980. During summer low flows in 1979 and 1980, 65 cross sections of the channel were surveyed to provide detailed measurements of existing channel conditions. Channel widths of 62% of the aggraded reaches were significantly greater ($\alpha = 0.05$) than those for nonaggraded reaches.

INTRODUCTION

A stream channel integrates many influences within a drainage basin. Sediment availability, stream discharge, stream gradient, vegetation, soils, and geology influence its morphology. The study of temporal and spatial variations in channel characteristics should therefore not be limited to the stream alone but should encompass the response of a stream system to factors within the entire drainage basin.

In the forested mountains of western Oregon and the Pacific Northwest, the primary land use is timber production; thus timber harvesting and road construction have been studied for their effect on sediment production and landscape alteration [e.g., *Swanson and Dyrness*, 1975; *Beschta*, 1979; *Reid et al.*, 1981; *Rice and Datzmann*, 1981]. However, the influence of harvesting activities upon channel characteristics of large streams has not been well documented because of the extensive data requirements and the lack of consistent methodology.

Fluvial systems appear to behave randomly because many watershed variables (e.g., steam discharge, sediment availability and transport) are stochastic [*Heede*, 1980]. Past studies [*Langbein and Leopold*, 1964; *Maddock*, 1970; *Thornes*, 1979] stress the variety of responses of streams to changes in the drainage basin, and theories combining principles of fluvial morphology and fluvial mechanics have been deemed insufficient [*Bray and Kellerhals*, 1976] for predicting channel response to perturbation in the stream system. However, *Schumm* [1971, 1973] has provided several relationships which indicate channel responses to changes in water and bedload discharge:

$$Q_w \simeq \frac{b,\ \lambda,\ d}{s}$$

$$Q_s \simeq \frac{b,\ \lambda,\ s}{d,\ p}$$

where

Q_w mean annual discharge or mean annual flood;
Q_s bed material transport;
b channel width;
λ channel wavelength;
d channel depth;
s channel gradient;
p sinuosity.

Even though flood peaks are not explicitly identified in the equations, their effects may well have the same influence as Q_w [*Schumm*, 1977]. An increase in Q_w or Q_s, either individually or in unison, should cause increases in channel width. However, sinuosity is related, inversely, only to Q_s. Both channel width and sinuosity can be measured on aerial photographs and were used for evaluating channel responses in this study.

Though it is difficult to separate the effects of management practices on a channel from 'natural' channel changes after hydrologic events, documentation of the morphological response of streams can help in assessing their relative importance. We undertook such a historical study within the basin of the Middle Fork Willamette River (MFW) to assess the importance of land use and floods in shaping the MFW channel. During the last several decades, changes in the morphology of the MFW River has caused concern among local land managers because of degradation of the aquatic habitat and riparian resources. The photograph series in Figure 1 illustrates the magnitude of channel changes between 1946 and 1967. Morphologic changes wrought during a major flood in December 1964 can be readily discerned. In this study, we hoped to provide a more complete understanding of the relation between watershed factors and channel morphology of the MFW River between 1936 and 1980—a time span which includes a high-magnitude, low-frequency flood and the initiation of timber harvesting and roading in the basin.

STUDY AREA

The MFW River above Hills Creek reservoir drains approximately 668 km^2 of mountainous terrain within the Cascade Mountains of western Oregon (Figure 2). The USDA Forest Service administers 90% of the watershed; the remaining 10%

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is privately owned. The focus of this study was a 25-km length of the MFW River immediately upstream of Hills Creek Reservoir (Figure 2). The watershed lies within two vegetation zones of the Douglas fir Region of the Pacific Northwest [*Franklin*, 1979]. Below 1000 m the vegetation is typical of the Western Hemlock Zone; above 1000 m it is typical of the Pacific Silver Fir Zone. Elevations in the MFW watershed range from 260 to 2664 m above sea level.

Annual precipitation averages approximately 1500 mm. During winter months, the snowpack is transient and of variable extent within lower elevations of the watershed.

Mass soil movements are dominant erosional processes in the MFW watershed. Unstable soil types, mapped by *Legard and Meyer* [1973], are associated with the Little Butte Volcanic Series (tuff, breccia, basaltic andesite, and basalt of Oligocene and Miocene age).

PROCEDURES

Watershed Inventory. To index changes in land use, timber harvest areas in 5-year intervals from 1945 to 1979 were computed from Willamette National Forest records (the Total Resource Inventory Data File). Road density was computed from historical maps.

Mass soil movements, because of their importance in affecting fluvial sediment loads and hence channel responses, were also inventoried. This inventory of the MFW watershed, made from aerial photographs of 1959, 1967, and 1972, was restricted to landslides occurring near the MFW River and its major tributary streams. Data for timber harvest and road density were used to determine the approximate watershed area of each of three land use categories (forest, clearcut, and roads) for calculating areal frequencies of landslides. An average cleared width of 15 meters was assumed for roads.

Large flow events may cause pronounced changes in channel characteristics. Thus peak flows greater than 100 $m^3 s^{-1}$ recorded for the MFW River between 1958 and 1980 at U.S. Geological Survey gaging station 14144800 (taken from the U.S. Geological Survey Water Resources Data for Oregon, 1959–1980) were assessed over the period of record. A regression of total storm precipitation and peak flow was developed to remove the influence of precipitation amounts on peak flows. The flow residuals were tested for the hypothesis that changes in the occurrence and magnitude of peak flows were correlated with increased land use. Storm precipitation associated with each peak flow was calculated from records for Toketee Falls, Oregon (from the National Oceanic and Atmospheric Administration Climatological data for Oregon, 1958–1980) from a gage at 740-m elevation 24 km south of the MFW River. We defined total storm precipitation as the amount occurring on the day of peak flow and the preceding two days.

Channel Evaluation. Temporal changes in channel pattern were measured on aerial photographs from 1936, 1946, 1959, 1967, 1972, and 1980. Scale of the photographs ranged from 1:12,000 to 1:20,000. On each of 25 1-km reaches upstream of Hills Creek Reservoir (Figure 2), 10 equally spaced segments representing 100-m intervals were marked for measuring unvegetated channel width and for counting low flow channels as an index to channel braiding. Organic debris visible within the unvegetated channel area was counted on each reach, and channel sinuosity was measured.

Channel characteristics measured from each photoset provided the basis for evaluating channel changes (if any) on the subsequent photo set. Increases in either channel width or braiding index may indicate aggradation. *Heede* [1980] argues that deposition is required to initiate drastic increases in channel width and braiding. Because aerial photographs indicate that until 1946 the MFW River was essentially a single-thread channel, we assumed that evidence of local aggradation was relatively strong if reaches showed both widening and an increase in the number of low flow channels.

Spatial variations in channel morphology were additionally assessed during 1979 and 1980, when 65 cross-sectional profiles were surveyed along the MFW River (Figure 2). Channel width, average channel depth, and cross-sectional area of flow at bankfull stage were measured. Local channel aggradation was noted by the following criteria: buried trees, braided channel pattern, and midchannel bars of alluvium higher than banks. The absence of these criteria defined nonaggraded sections, which were characterized by well-defined and vegetated channel banks.

At each profile location, we also sampled the streambed surface, using a technique described by *Wolman* [1954]. *Heede* [1980] states that changes in size of bed material is indicative of changes in size of bedload transported by the stream.

Statistical Analyses. An assessment of the effect of peak streamflows upon channel morphology began with a regression model relating peak streamflow and storm precipitation. A model of the form

$$Y = aX_1{}^b \tag{1}$$

met the assumptions of regression, where Y is the peak flow in cubic meters per second, X_1 is the storm precipitation in millimeters, and a and b are regression coefficients.

Because an analysis of the flow residuals of this model indicated a time trend in the data, a time variable was added to the regression, giving an equation of the form

$$Y = aX_1{}^b e^{cX_2}, \tag{2}$$

where Y and X_1 are as previously defined; X_2 is the elapsed time between date of peak flow occurrence and initial peak flow of the data set in days, a, b, c, are regression coefficients, and e is base of the natural logarithm.

Paired t tests were used for statistical comparison of average channel width and the number of low flow channels. Regression functions relating drainage area (independent variable) of each cross section location and channel dimension (dependent variables) were developed for nonaggraded cross sections. Using these functions, we compared channel dimensions of aggraded reaches to those of nonaggraded reaches [*Park*, 1977]. Differences in mean gravel size between aggraded and nonaggraded reaches were examined with an unpaired t test.

RESULTS AND DISCUSSION

Landslide Frequency. Locations of landslides within the MFW Watershed for 1959–1972 are shown in Figure 2. The number of new landslides on 1967 photographs is 3 to 9 times greater than on any other photograph set (Table 1). These landslides averaged 400 m^2. Presumably, most of those visible on the 1967 photographs were triggered during the 1964 storm. Landslides of 1959–1967 occurred in clearcuts or near roads 23 and 27 times more frequently, respectively, than in forested areas, which suggests that land management activities in the

Fig. 1. (Opposite) Aerial photographs illustrating changes in channel characteristics of approximately 1 km of the Middle Fork Willamette River at its confluence with Staley Creek. The Middle Fork flows from right center of photographs to left.

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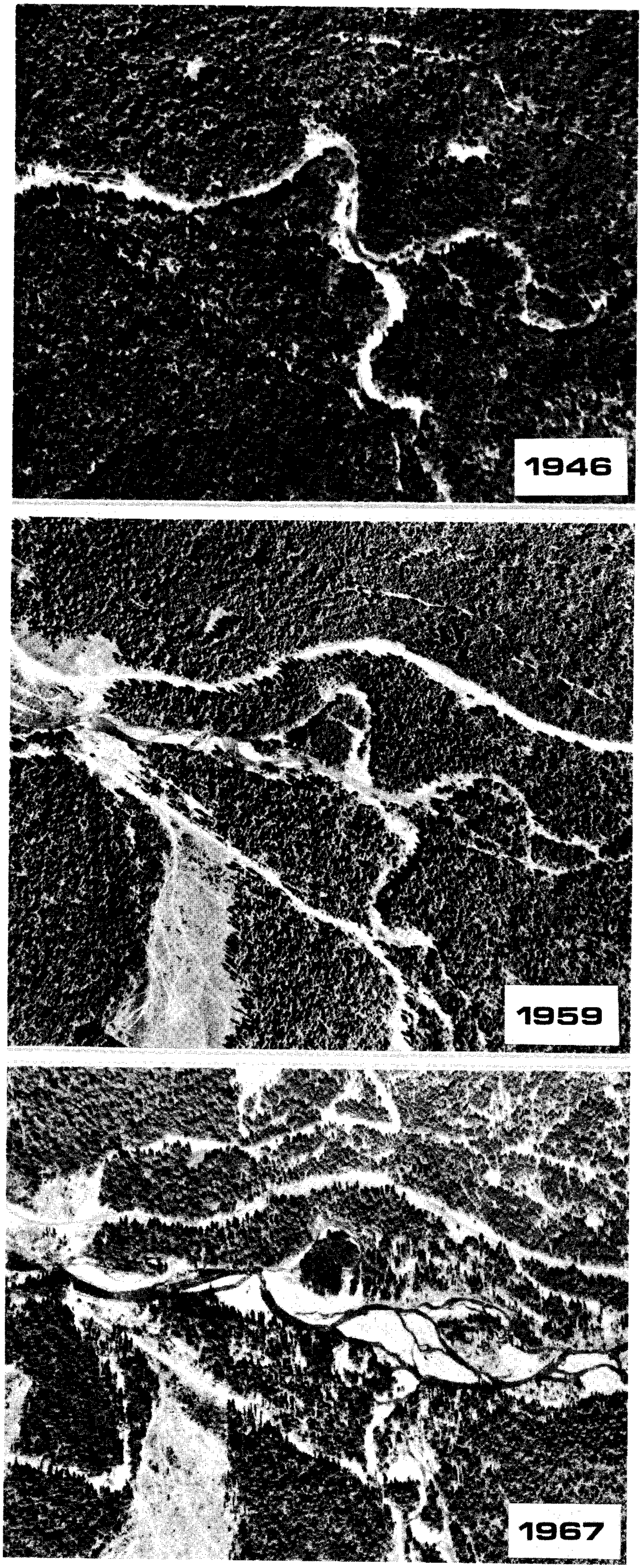

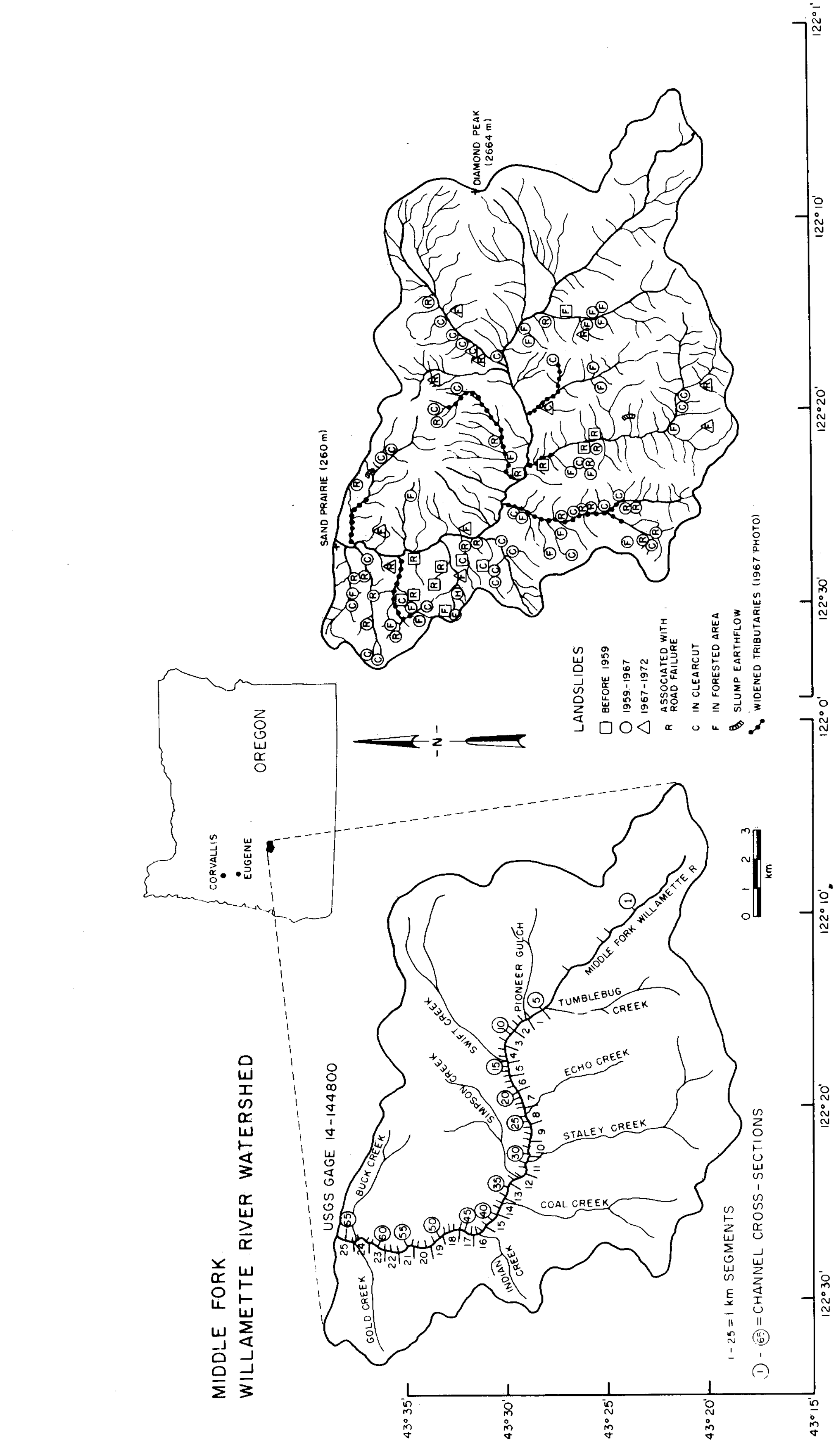

Fig. 2. The Middle Fork Willamette River watershed showing the 25 1-km segments evaluated for channel change (1936–1980) and the 65 channel cross sections surveyed for aggradation. Dates of landslides are based on aerial photos.

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TABLE 1. Landslide Frequency for the Middle Fork Willamette Basin and Other Areas in the Oregon Cascade Mountains

Land Use Category	Time Period	Number of Events	Events, km^{-2} yr^{-1}			
			Middle Fork*	Blue River	H.J. Andrews	Alder Creek
Forest	before 1959	2				
	1959–1967	18	0.03(1)	0.012	0.025	0.023
	1968–1972	5	0.01(1)			
Clearcut	before 1959	3				
	1959–1967	27	0.68(23)	0.012	0.097	0.267
	1968–1972	3	0.13(13)			
Road	before 1959	8				
	1959–1967	21	0.87(27)	1.26	1.38	8.33
	1968–1972	5	0.10(10)			

Other areas are the Blue River drainage [*Marion*, 1981], H. J. Andrews Experimental Forest [*Swanson and Dyrness*, 1975], and Alder Creek [*Morrison*, 1975], all in the Willamette National Forest.

*Parenthetical values are the frequency in relation to the forest category.

basin increased the effect of the rare 1964 hydrologic event on landslide frequency.

However, the forest canopy may obscure some of the landslides in the forest land use category. No ground surveys of landslide activity, necessary for accurate determination of frequency, were conducted in this study. Landslide frequencies calculated from aerial photographs were assumed to be representative. This assumption appears valid because of the similarity between the frequency calculated for the MFW Basin from aerial photographs and the frequency in three studies which included 'ground truthing' of landslide occurrence (Table 1).

The influence of landslides upon channel morphology is dependent upon the amount and particle size distribution of sediments delivered to the stream. *Swanson and Dyrness* [1975] found that although landslides were more frequent on clearcuts, sediment volume was less than for landslides in forested areas. They also reported that the average volume of road-related landslides was lower than the volume in forested areas. However, total soil transfer was greater for road-related landslides than for landslides in forested areas because of the greater frequency in the road category. *Morrison* [1975] and *Marion* [1981] report similar results, which indicates that roads have a greater impact upon the soil transfer rate than landslides associated with clearcuts.

Between 1959 and 1967, most road-related failures in the MFW watershed occurred within the Little Butte Volcanic series. Many of the 1964 mass failures unloaded large volumes of sediment directly into the MFW River and its major tributaries; hence the impact of these sediments on the channel would be more pronounced than failures occurring in places well removed from the drainage system. Landslide frequency in the road and clearcut categories were not appreciably different on the watershed. If the relative rates of soil transfer for these two categories is comparable to those indicated by *Morrison* [1975], *Swanson and Dyrness* [1975], and *Marion* [1981], landslides from roads probably contribute a slightly greater percentage of available sediment to the main stream and tributaries of the MFW River.

Land Use and Peak Flows. The earliest recorded logging activity in the MFW Watershed was in 1945. Harvesting activities for 1945–1979, summarized in Figure 3, reflect only timber harvesting on National Forest land. With few exceptions, clearcutting was the silvicultural prescription for harvesting on the MFW Watershed. In general, road building coincided with harvesting. However, while the rate of harvesting showed a slight decline during the late 1970's, road building increased at a relatively faster rate (Figure 3). In addition to establishing relationships between landslide occurrence in roads and clearcuts, we attempted to evaluate the influence of road building and forest harvesting during the 1960's and 1970's on flood magnitude.

The greatest peak discharge recorded for the MFW River, on December 22, 1964, was estimated to be 1130 m^3 s^{-1} (SE = 37%), with a corresponding recurrence interval of 100 years [*Harris et al.*, 1979]. Interpolation from peak discharges of the 5- and 10-year recurrence interval, as given by the U.S. Geological Survey equations [*Harris et al.*, 1979], yields a recurrence interval of approximately 8 years for the annual peak flows of the 1971, 1972, and 1978 water years. The occurrence of the three floods in a relatively short time span made Forest Service personnel concerned as to the effect of timber harvesting on the magnitude of flows (J. Christner, unpublished report, 1981).

To investigate the possible existence of a relationship between land use and the magnitude of peak flows, we first correlated peak flow magnitude Y for events greater than 100 m^3 s^{-1} with storm precipitation X_1 in millimeters and established the following relationship:

$$Y = 7.08\ X^{0.7784} \qquad r^2 = 0.38 \tag{3}$$

where the number of peak flows is 46. The temporal distribution of flow residuals revealed a time trend in the data; a time variable (X_2) in days from initial peak of the series was added to the model:

$$Y = 5.48\ X_1{}^{0.7757} e^{0.7442 \times 10^{-4} X_2} \qquad r^2 = 0.48 \tag{4}$$

The addition of X_2 was significant at the $\alpha = 0.01$ level.

Although we can show a trend of increasing peak flows with time, the strength of this trend is limited by several factors relating to our statistical procedures. First, in the original regression function of precipitation and peak flow the distribution of the residuals was skewed, a problem that was ameliorated but not eliminated by a logarithmic transformation of the data. Second, the variation in peak flow magnitude explained by the storm precipitation conditions is low ($r^2 = 0.38$). This suggests that other variables (perhaps form of precipitation, precipitation intensity, or snowpack conditions) should be

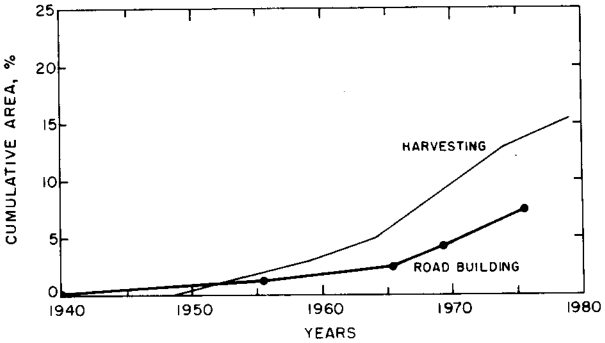

Fig. 3. Percentage of total area of the Middle Fork Willamette Basin affected by timber harvesting and road building.

quantified in conjunction with storm precipitation to develop an improved predictive model for peak flow magnitude. Lack of reliable data of this type for the MFW drainage made a more detailed analysis impossible. The period of record (22 years) is a third limiting factor. Use of a partial series of peak flows increased the data available for analysis, but the intrinsic variability of precipitation and peak flow events suggests that a longer period of record would be more suited to this type of analysis.

The analysis of precipitation and peak flow data indicates that peak flow magnitude has been increasing over the past 22 years. This time encompasses an active period of timber harvesting and road construction within the MFW drainage; hence a causal relation between the increasing rate of timber harvesting and the occurrence of relatively high flows might be inferred. One hypothetical mechanism for increased peak flow occurrence, described by *Harr* [1981], is based upon an assumption of greater snowmelt from clearcut areas than from forested areas during rain-on-snow events. But a relationship between peak flows and land use is subject to debate on several points. First, earlier research on small basins indicates that annual peak flow magnitude is not significantly influenced by harvesting activities [*Rothacher*, 1973; *Harris*, 1973]. However, the large size of the MFW Basin, relative to the other research watersheds, constrains direct application of the earlier results. Second, recurrence intervals calculated for flows of various magnitudes represent an average based on probability distributions developed for flood series. These average return intervals cannot be used to predict the pattern of occurrence of flows [*Linsley et al.*, 1975]. Last, greater peak flow from clearcut areas than from forested areas during rain-on-snow events in western Oregon has not been clearly established; *Harr and McCorison* [1979] have demonstrated decreased peak flow on clearcut areas in the western Cascades. Obviously, the hypothesized mechanism of alteration requires further study.

Climatic changes can also alter the peak flow pattern of a stream system. *Harr and Christner* [1982], after studying long-term precipitation records for the Cascade Mountains of western Oregon, concluded that no significant climatic change was observable over the last 35 years.

Temporal Channel Variation. From 1936 to 1946, significant increases in both channel width or number of low flow channels did not occur simultaneously in any 1-km reach. However, average channel width increased significantly in 13 kilometers of channel during the 1946–1959 period (Figure 4). The number of low flow channels (as well as channel width) increased significantly in reach 21 over this same period. The junction of Bohemia Creek and the MFW River is located in reach 21. A road crossing was constructed in reach 21 during the 1946–1959 period and two small landslides associated with roads in an adjacent drainage occurred before 1959. The channel morphology changes indicated from photographs of reach 21 may have been a direct result of these activities.

Changes in widths of unvegetated channels for 1959–1967 illustrate the influence of the December 22, 1964 flood (recurrence interval ≥ 100 years). Width increased significantly in all but 8 km of channel between 1959 and 1967, the increases ranging from 25% to 250% (Figure 4). No major changes were found for 1967–1972, but a trend towards decreased widths appeared in 1972–1979. Regrowth of the riparian vegetation after the channel widening in the 1964 flood could explain this latter trend. The impacts of rare, high-magnitude flows upon width, and the recovery of the channel width to preflood dimensions are discussed by *Wolman and Gerson* [1978]. They demonstrated that channel widths of streams in humid regions return to preflood dimensions within 10 years of the event. *Lisle* [1981] indicates that this estimate of recovery time may not be appropriate for areas having highly seasonal rainfall and coarser sediment, such as the MFW drainage.

The photograph comparisons for 1959–1967 (Figure 4) also show significantly more flow channels on approximately 25% of the 1-km reaches. Channel width and number of low flow channels increased below the confluence of tributaries and the MFW River (reaches 5, 6, 8, 11, and 14). Significant channel changes at these tributary junctions with the main stem of the river indicate they are most susceptible to channel changes during infrequent peak flows. Hillslope erosion and bed sediment transport in tributary channels during the major storm in 1964 appear to have influenced the channel morphology at these locations.

Reach sinuosity did not vary greatly from 1936 to 1980, the one exception being reach 11 (at the confluence of Staley Creek and the MFW River) during 1946–1959. Sinuosity of this reach decreased sharply from 1.22 to 1.01 during this time as a result of development of a meander cutoff, first visible in the 1959 photograph (Figure 1).

In the tally of large organic debris (consisting mainly of tree-length logs) on each 1-km reach of the MFW channel (Table 2), downstream transport of debris by 1964 floodwaters was indicated by the substantial reduction in number of pieces from 1959 to 1967. The reduction occurred during a period of pronounced channel widening which should have increased the availability of large woody debris to the channel. Undocumented salvage sales after the 1964 flood may also have contributed to the reduction, or where channel aggradation occurred, debris may have been buried by sediment. Also, photographic quality varied between series; the 1967 photographs were of lower resolution, which made it more difficult to identify individual pieces of debris. Another reduction in large debris pieces between 1972–1979 probably reflects the results of

TABLE 2. Pieces of Large Organic Debris Tallied on Aerial Photos of the Middle Fork Willamette River

Photo Date	Reaches	Number of Pieces
1936	15–25	74
1946	1–25	139
1959	1–25	126
1967	1–25	94
1972	1–25	157
1979	1–25	114

Each reach is 1 km.

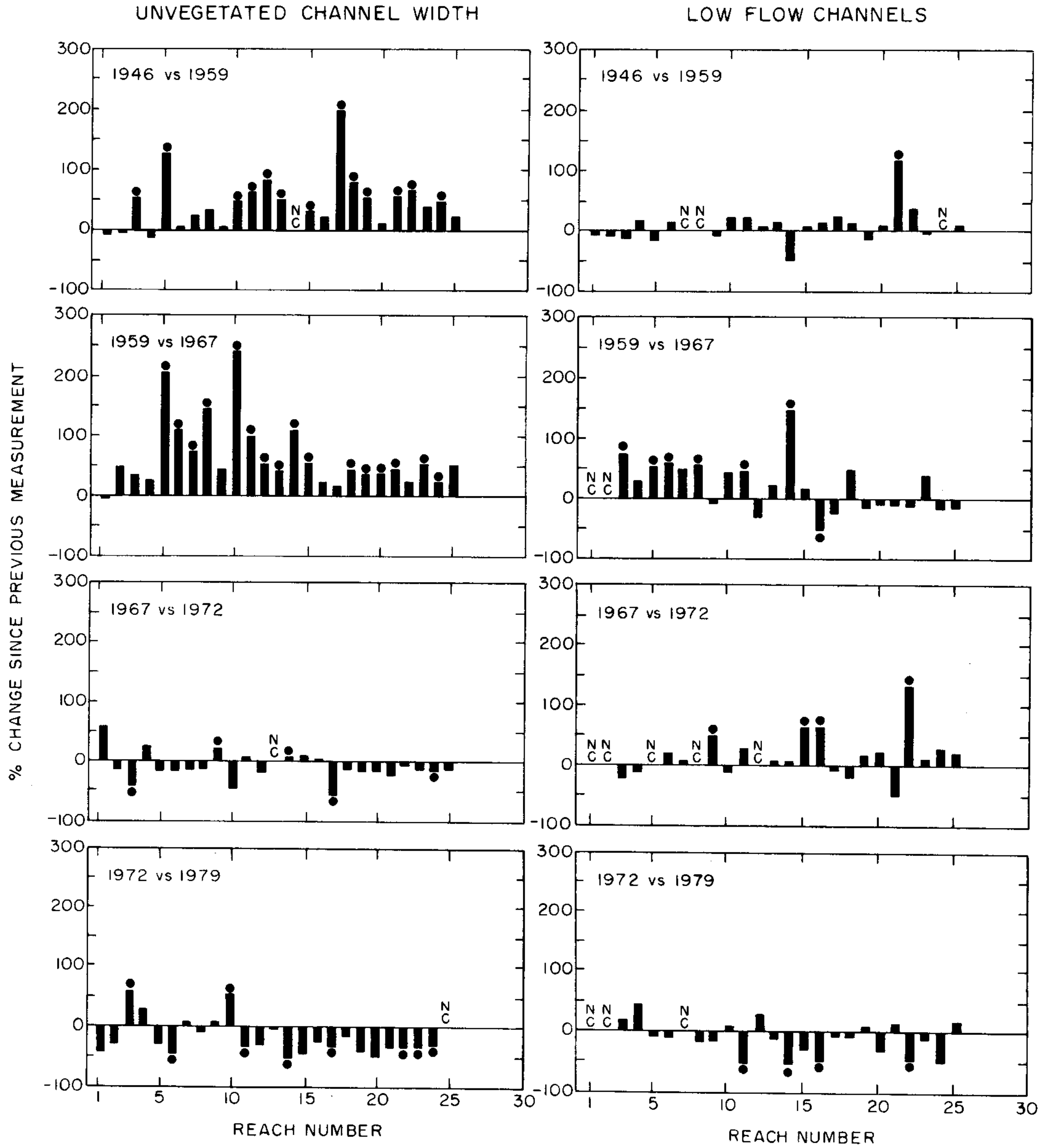

Fig. 4. Average width of unvegetated channels and average number of low flow channels of the Middle Fork Willamette River, 1946–1980. NC indicates no change; solid circles indicate significant change ($\alpha = 0.05$).

a program initiated by the Forest Service (R. Ragon, unpublished report, 1972) to remove large woody debris from the flood plain of the MFW River.

Large organic debris is an important factor influencing channel morphology and fish habitat in small mountain streams [*Swanson et al.*, 1976]. Large debris deflects flows, alters bed roughness, and can have a pronounced effect on the routing of bedload sediments through the channel system. Streamside management by the Forest Service has reduced this component in the stream ecosystem, as such management has consisted primarily of salvaging logs from the channel and flood plain, cutting tree-length logs into smaller pieces for burning, and removing mature trees on and adjacent to channel banks. Although the effect of large woody debris on channel characteristics and fish habitat of larger streams is not easily defined, these activities may have had an important effect on bank stability and channel characteristics of the MFW River.

Geometric mean diameter of the armor layer was significantly smaller for aggraded reaches (40 mm) than for nonaggraded reaches (51 mm). The smaller bed material reflects a decrease in channel slope at these locations, presumably a result of aggradation.

Spatial Channel Variation. Channel survey and bed material measurements were limited to those sections of the MFW River that could be waded during summer low flows (perhaps 75% of the length of stream studied). This prevented measurement in portions of the channel characterized by pools (i.e., depths > 1.5 m) or by relatively steep channel gradients with high flow velocities. Thus the field measurements do not necessarily provide a complete characterization of aggraded and nonaggraded reaches.

Channel cross sections (Figure 1) at the 53 nonaggraded reaches along the MFW River were used to develop the relationship shown in Figure 5. Approximately two thirds of the aggraded reaches have significantly wider channels than could be predicted from regression of nonaggraded reaches. This analysis tends to confirm the correlation between increased

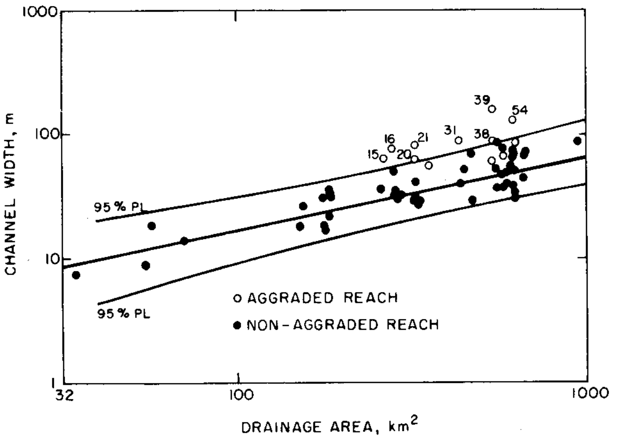

Fig. 5. Relationship of bankfull channel width and drainage area of the Middle Fork Willamette River Basin. The regression line and 95% prediction limits were developed from data for nonaggraded reaches. Channel widths and associated drainage area for aggraded reaches are plotted for comparison with the regression relationship.

channel width and aggradation, suggesting that increases measured from aerial photographs can be interpreted as indicators of local aggradation.

High flows alone might also remove riparian vegetation along the channel. On aerial photographs, the channel would appear wider after high flow than before even though aggradation did not occur. Because water and sediment discharge may change simultaneously, determination of relative contributions of individual variables upon channel width is further complicated. However, we would suggest that the channel has responded primarily to changes in sediment availability (increased by mass failures) in the fluvial system rather than to high flows. This hypothesis is reinforced by the channel-width changes demonstrated in Figure 4. If high flows were the dominant mechanism increasing channel widths, more uniform increases in width along the entire 25 km of channel might have been expected. But because channel changes are generally localized in contiguous sections associated with sediment input from mass failures, we would argue that sediment load has the more important effect on channel changes along the MFW River.

CONCLUSIONS

A trend of increasing magnitude of peak flows appears during a period of relatively rapid increase in harvesting and roading in the MFW watershed. Unfortunately, additional data on precipitation form and local climatic conditions that might improve this analysis were unavailable for the watershed. The influence of man's activities upon mass soil movements and channel changes within the MFW basin were most pronounced during and after the 1964 flood. The effect of this rare hydrologic event and the landslides associated with it was readily visible on aerial photographs. Road building and forest harvesting increased the amount of sediment available to the stream, and channel morphology changes were primarily a response to increased sediment delivery.

Measurements of aerial photographs indicated the following changes in channel morphology of the MFW River.

1936–1959. Increases in channel width are apparent in several locations. A large change appears at the MFW junction with Staley Creek. Other indicators of channel aggradation are apparent near the mouth of Bohemia Creek.

1959–1967. Significant increases in channel width (25% to 250%) and braiding occur in conjunction with the 1964 flood, most prominently at the junctions of the MFW and Coal Creek, Staley Creek, Echo Creek, and Swift Creek.

1967–1972. Minor decreases in channel width predominate; only a few increases in channel width appear.

1972–1980. Trend of decreasing channel width continues; the number of low flow channels decreases significantly in 4 of 25 reaches.

Aggradation continues at several locations along the MFW River, as suggested by an analysis of channel shape factors in 1979 and 1980. The aggraded areas correspond to those found on aerial photographs after the 1964 flood.

This historical record of channel morphology suggests that aggradation of the MFW River during the December 22, 1964 flood was greatest at the junctions of the river and its major tributaries. Sources of the depositional sediment are upstream channel bed material and landslides. Landslides within the MFW drainage are most frequent in the Little Butte Volcanic Series that occurs predominantly along the river. Landslides from clearcuts and roads were approximately 23 and 27 times more frequent, respectively, than those in forested areas during the 1964 hydrologic event. Channel changes may have been further influenced by salvage logging and debris removal along the MFW River; however, additional research is needed to demonstrate the effect of streamside management on channel characteristics and to identify causal relationships.

It is our opinion that changes in morphology of the MFW channel 1936–1980 are a result of the relatively high sediment input developed during the 1964 storm and not of high flow per se. The type and direction of channel changes measured in this study are consistent with the concept of complex response of drainage systems proposed by *Schumm* [1973, 1977]. Although channel widening would have occurred 'naturally' during the 1964 flow event, accelerated sediment input resulting from land use may have significantly increased the channel response. Unfortunately, the magnitude of increase resulting from the management related erosion could not be quantified.

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