

AN ABSTRACT OF THE THESIS OF

Sandra E. Ryan-Burkett for the degree of Master of Science in
Geography presented on March 3, 1989.

Title: Riparian Canopy and Channel Response to Hillslope
Disturbance in Elk River Basin, Southwest Oregon

Abstract approved: _____ **Signature redacted for privacy.**
Charles Rosenfeld

Elk River is a sixth order stream, draining a 200 square kilometer basin in the Klamath Mountain province of southwestern Oregon. Timber harvesting began in the basin during the 1950's, with peak removal of wood occurring in the mid to late 1960's. This activity lead to an increase in the frequency of landsliding and surface erosion. The downstream effects of this increase in sediment were evaluated by interpreting aerial photography spanning the period 1956 to 1979. Opening or enlargement of the riparian canopy cover was used as an indicator of sediment impacts.

Results indicate that in most basins, changes in downstream channel conditions could not be directly linked to the increase in sediment delivered from harvested areas. Opening on higher order channels occurred throughout the study period, but did not exhibit patterns indicative of a large pulse of sediment moving through the system. Rather, opening

in fourth to fifth order channels was attributed to the interaction between local sediment sources and channel morphology, with unconstrained, flat channel segments exhibiting chronic opening. The distribution of constrained and unconstrained channel reaches was defined by a Channel Morphology Index (CMI), which compared relative width and gradient changes to channel averages.

A 100-year event in 1964 did not produce effects in Elk River Basin on the same order of magnitude as other basins in the Pacific Northwest. Downstream effects were important in a few areas where landslides and high rates of surface erosion were directly linked to opening and channel widening downstream. Limited channel response to hillslope disturbance in Elk River Basin over the period 1956-79 was attributed to four factors: lack of debris flows in most areas of the basin, channels constrained by competent hillslopes and bedrock limiting the extent of opening, channel conditions inherited from storms prior to 1956, and essentially pristine conditions over much of the basin at the time of the 1964 storm.

Finally, sequential air photo interpretation proved useful in deciphering disturbance history and analyzing processes which create downstream effects.

Riparian Canopy and Channel Response to Hillslope Disturbance in Elk
River Basin, Southwest Oregon

by

Sandra E. Ryan-Burkett

A Thesis

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed March 3, 1989

Commencement June 1989

APPROVED:

Professor of Geography in charge of major

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Date thesis is presented March 3, 1989

ACKNOWLEDGMENTS

This project was funded and supported in part by the Coastal Oregon Productivity Enhancement project (COPE), fisheries enhancement group and by Research Work Unit 4356, USDA Forest Service Pacific Northwest Research Station, Corvallis, OR. Aerial photographs and maps were provided by the Siskiyou National Forest, Westside Engineering Zone and by the University of Oregon map library. The State of Oregon Elk River Fish Hatchery and the Oregon State University Department of Fisheries and Wildlife provided equipment and facilities during the field portion of this study.

I am gratefully indebted to Dr. Gordon Grant for introducing me to his RAPID technique and for encouraging me to undertake this project in the Elk River Basin. His faith and enthusiasm were the driving force in the evolution of a "quick and dirty" research paper into a two year thesis project. I also extend a special thanks to Dr. Frederick Swanson for providing comments and insight into the development and organization of this study. Additional editorial assistance and comments were provided by my other committee members; Drs. Donald Farness, Jon Kimerling, and Charles Rosenfeld.

Several others also merit mention for their assistance in conducting research and in the preparation of this paper. Margaret McHugh's study on landslides in the Elk and Sixes basins provided an excellent base to begin my research from and saved me much time and effort. Chris Frissell and Rich Nawa of the OSU Department of

Fisheries and Wildlife, and Cynthia Ricks of the Siskiyou National Forest provided lively discussions and insight into the interaction between forest management, sediment impacts, and fish habitat. Drs. Gary Lamberti, Stanley Gregory, James Sedell, and Gordon Reeves also provided ideas on these issues through coursework and discussions. Finally, my field partners and trailer mates, Bruce Hansen and Mark Fedora, deserve a special thanks for their attention to detail and humor in attending to the business at hand during the summer field season, 1987.

Above all, I would like to thank my husband, Tom Burkett, for his unending support, confidence, and encouragement in this endeavor.

TABLE OF CONTENTS

	page
INTRODUCTION	1
ASSESSING DOWNSTREAM EFFECTS OF HARVEST	3
ACTIVITIES ON STREAM CHANNELS	
Processes Creating Downstream Effects	4
Interpreting Downstream Effects from	7
Aerial Photography	
Analysis of Downstream Effects	8
PHYSICAL CHARACTERISTICS OF ELK RIVER BASIN	14
Location and Topography	14
Geology and Geomorphic Processes	14
Climate	19
Timber and Fisheries Resources	21
Management History	23
METHODS	26
Air Photo Investigation	28
Field Investigation	30
RESULTS	32
CHAPTER 1. OVERALL PATTERN OF OPENING IN	32
ELK RIVER BASIN	
CHAPTER 2. LANDSLIDING AND CANOPY OPENING IN	39
LOW ORDER BASINS	
Processes of Canopy Opening in Low Order	41
Tributaries	
Role of Landslides and Surface Erosion	44
in Generating Downstream Effects	
CHAPTER 3. OPEN CANOPIES IN FOURTH TO FIFTH	52
ORDER CHANNELS	
Role of Channel Morphology in Promoting	52
Sediment Deposition and Open Canopies	
Channel Morphology and Canopy Opening	55
Change in Pattern of Opening	56
Large Storms and Pattern of Opening	65
Timber Harvesting and Pattern of	67
Opening	

CHAPTER 4. MAIN CHANNEL AND OFF-FOREST EFFECTS	69
Trends in Sedimentation on Main Stem Elk River	69
Distribution of Gravel Bars	70
Off-Forest Effects	76
 DISCUSSION AND CONCLUSIONS	 79
Summary of Results	79
Factors Contributing to Channel Response in Elk River Basin	82
Management Implications	84
 LITERATURE CITED	 88

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
1. Cartoon of sediment processes which create open canopies.	6
2. Photo of opening created by debris flow.	10
3. Photo of opening created by peak flow and sediment transport.	10
4. Photo of opening created by surface erosion (dry ravel).	11
5. Study layout - flow diagram.	13
6. Location map	15
7. Geology Map and legend	17
8. Climagraph, Powers, OR	20
9. Zones of highest salmonid production.	24
10. Timing and amount of harvesting in six basins inventoried.	25
11. Map of basins inventoried in study.	27
12. Relationship between area of basin harvested and area of channel opening.	34
13. Total length of open channels by order and by photo series.	36
14. Change in percent of channel length exhibiting opening over time.	37
15. Cartoon of angle of tributary junctions.	43
16. Initial site of disturbance in low order basins.	45
17. Lengths of openings generated by landslides.	47
18. Conceptual model of types of debris movement	49

19.	a, b, c. Channel morphology and chronic canopy opening on higher order channels.	57
20.	a, b, c. Change in opening between photo intervals in higher order channels.	61
21.	Map of main stem Elk River segments.	71
22.	Total number of gravel bars on main stem Elk River by photo series.	72
23.	Distribution of gravel bars in main stem Elk River by photo series.	74

LIST OF TABLES

<u>Table</u>		<u>page</u>
1.	Physical parameters of channel response.	9
2.	Peak flows, South Fork Coquille River, 1944-80.	22
3.	Canopy opening and forestry activity in ten tributary basins.	33
4.	Failure rates by terrane.	40

RIPARIAN CANOPY AND CHANNEL RESPONSE TO HILLSLOPE DISTURBANCE IN ELK
RIVER BASIN, SOUTHWEST OREGON

INTRODUCTION

There has been considerable debate in recent years on the issue of the downstream effects of timber harvesting on stream channels in the forested drainage basins of the Pacific Northwest. The discussion centers around the issue of whether or not these effects can be detected in stream channels and if they are, indeed, produced by upslope forest practices. Proponents of the argument for downstream effects point to studies which conclude that channel widening and aggradation occurred in coincidence with logging activity in a drainage basin (Nolan and Janda 1979, Lyons and Beschta 1983). Opponents of the argument suggest that these channel changes may have occurred without logging effects due to peak flows produced by large storms.

With the enactment of legislation in the mid 1970's, state and federal land managers were required to consider the off-site effects of planned activities and to assess potential cumulative watershed impacts. However, current methods for addressing cumulative effects use arbitrarily established limitations on the amount of basin harvested over a given period of time as a means of mitigation. This procedure, applied uniformly across a management area, fails to

consider differences in the inherent basin sensitivity to forest practices. At best, this method fulfills the legal requirement for addressing cumulative watershed impacts. At worst, arbitrarily scheduling and dispersing harvesting activities is an ineffective means of mitigating these effects and may be deleterious to the stream system and aquatic habitat they were employed to protect.

In order to effectively assess downstream effects, the spatial and temporal relationships between land management, hillslope processes, and channel conditions need to be evaluated. In this light, a time-series analysis was conducted to assess the location, timing, magnitude, and persistence of channel change in Elk River Basin using air photos taken over a twenty-three year period. An air photo interpretation technique based on the RAPID technique (Grant 1988) was used to link upslope disturbances with downstream channel changes. Both logged and unlogged basins were analyzed in order to separate the effects of timber harvesting from those which may have occurred under natural conditions.

ASSESSING DOWNSTREAM EFFECTS OF HARVEST ACTIVITIES ON STREAM CHANNELS

Cumulative watershed effects are persistent impacts, separated in time and space from the original site of disturbance. Alone, individual disturbances may not have a significant effect. However, when triggered simultaneously, as during a large storm, they can create serious environmental changes due to the synergistic interaction between the disturbances and subsequent impacts (Hagens et. al. 1986). Several types of cumulative effects are active in a watershed; this study focuses specifically on the off-site or downstream effects of forestry practices on the stream channel.

Downstream effects are produced when forestry activities induce changes in the way sediment, water, and woody debris are delivered to and move through a drainage basin. Logging and road construction produce changes in conditions on-site, including altering hillslope cover and contour, compacting soils, and reducing root strength. These changes alter local processes by reducing infiltration rates, expanding drainage networks, and increasing rates of mass movement, surface erosion and inputs of woody debris into the system. The changes in on-site conditions and processes can, in turn, alter the timing, rate, and amount of material movement through the drainage network. As a result, channels downstream become wider, shallower, and unstable, resulting in damages to structures and a loss of aquatic habitat in areas far removed from the original management site. In this manner, the effects of forest practices are translated downstream

and separated in time and space from the original source of disturbance.

Processes Creating Downstream Effects

In this study, the downstream effects of timber harvesting on fourth to fifth order channels in Elk River Basin were assessed using air photos to identify sediment impacts. Normally, sediment impacts on channels of this size are difficult to evaluate due to canopy cover over the channel. However, changes in channel condition can be readily identified on large scale air photos (greater than 1:24,000 scale) where hillslope disturbances and channel processes produce an opening in the riparian canopy cover. Opening appears on air photos as white streaks or a lack of vegetation in the drainage network.

Open canopies are produced by major disturbances, such as severe floods, landslides, debris flows, and excessive sedimentation, which uproot or increase the mortality of riparian vegetation. Though a vegetative response to disturbance, open canopies are useful as evidence of a change in the distribution of material in the drainage network, since the processes which create openings are movement of water, sediment, and debris.

Canopy closure occurs as a result of colonization of stable channel surfaces by vegetation and was used as an indication of recovery from disturbance. Revegetation occurs on less frequently inundated channel surfaces, usually at the edges of canopy openings distal to the channel. Gradually, revegetation encloses the active

channel, reducing the width of the opening and producing closed canopies exhibited on air photos.

Open canopies were used to interpret channel response in all parts of the basin, though the processes which create opening vary by location. Processes were classified by whether they occur in low order tributaries or higher order channels. Specific processes of opening and sedimentation are described in detail in Chapters 2 and 3 of the results section; a brief description of these processes follows (figure 1).

Opening in low order tributaries is attributed mainly to landslides generated in clearcuts and from roads. Landslides entering the low order channels may produce debris flows which scour the channel and uproot trees as they move downstream, producing an opening in the riparian corridor. Debris flows may eventually reach and move down higher order channels, continuing the track of scouring and battering downstream. The continuous opening produced by these flows is used to spatially link downstream channel changes to upslope harvesting activities. Deposition of debris flows occurs where channel morphology is no longer conducive to movement of the material due to channel widening, decrease in gradient, and sharp bends or changes in channel direction (Benda 1985, Nolan and Janda 1979). Opening in higher order channels may also result from peak flows and sediment transport which disturbs and removes vegetation from channel surfaces, undercuts terraces, and generates bankslides.

Open canopies can also be attributed to surface erosion - specifically, dry ravel and shallow failures of stony soil material

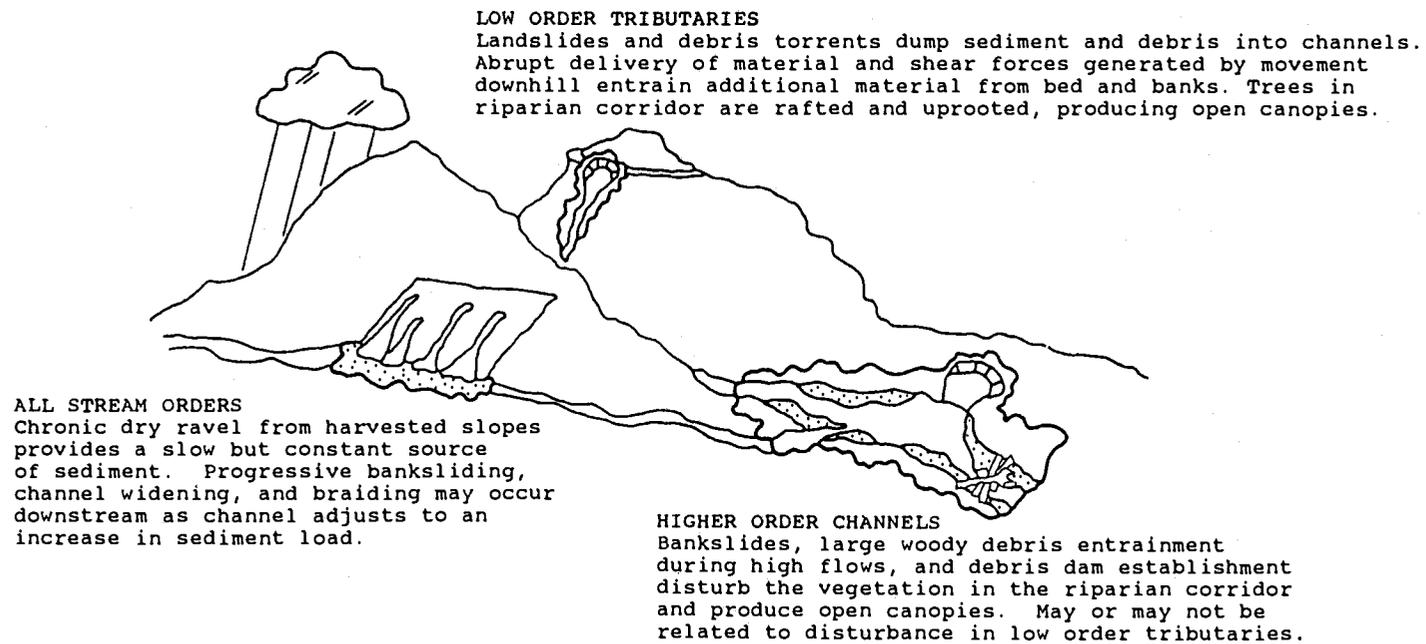


Figure 1. Cartoon of processes which create open canopies.

from harvested slopes. While the input of material is not rapid, it constitutes a locally significant source of material and produces channel widening where input overwhelms channel capacity. Dry ravel is generally limited to harvested areas underlain by sedimentary terrane in Elk River Basin. As a result, opening produced by dry ravel is not exclusive to either high or low order channels, but rather is influenced by the distribution of clearcuts in these terranes.

Landsliding and peak flows are not mutually exclusive processes. Both can occur during large storms and channel response may result from both influences. Rates of landsliding are often exacerbated by large floods (Swanson and Dyrness 1975, Morrison 1975, Marion 1981) while the impacts of floods can be more severe when landslides and debris flows are produced during the storm (Kelsey 1980). Still, the distinction between channel changes produced primarily by sediment delivery or by peak flows is important. Mitigation measures used to limit management impacts for peak flows are generally ineffective for debris flows (Costa and Jarrett 1981). Yet, debris flows appear to be more effective in generating downstream effects in some regions (Grant 1986) and need to be accounted for in designing effective mitigation strategies.

Interpreting Downstream Effects from Aerial Photography

The sources and processes which produce open canopies can be identified by several physical parameters interpreted from air photos

(table 1). These parameters include (1) the presence or absence of mass movement at the initial site of opening, (2) the degree of physical linkage or CONTIGUITY between the initial site of opening and the channel response downstream, (3) the extent of open canopies and degree of CONTINUITY of opening in the discontinuous portion of the channel, and (4) the changes in width of opening downstream. Though there is some overlap between parameters and no one parameter is distinctive enough for identification of the source of channel change, the overall pattern of opening is diagnosed by examining the combination of several parameters (Grant 1986).

For example, opening produced by landslides/debris flows are identified in low order basins by a headscarp at the initial site of opening with a moderate to long continuous opening, decreasing in width downstream (figure 2). Openings produced by peak flows are generally limited to higher order channels, exhibit no mass movement at the initial site of disturbance, and are variable in width downstream (figure 3). Openings produced by ravel slopes have small or nonexistent headscarps, are of variable length, and generally decrease in width away from the initial site of opening (figure 4).

Analysis of Downstream Effects

The sources, linkages, and patterns of opening were analyzed in order to evaluate the effectiveness of different sources of material in creating downstream effects. Two assumptions are implicit in this relationship: (1) different sources of material delivery to the

Table 1. Physical parameters of channel response, indicative of sources of material which can be interpreted from aerial photography (from Grant 1988).

Material Source	Mass Movement at Initial Disturbance Site	Length of Continuously Open Reach	Pattern in Downstream Channel	Change in Width Downstream from Initial Site
Peak Flows	no	variable	continuous to patchy	increase or constant
Surface Erosion	no	short	patchy	decrease
Landslides	yes	short to moderate	continuous	decrease
Debris Flows	yes	long	continuous	decrease
Woody Debris	maybe	variable	continuous to patchy	increase or constant



Figure 2. Example of how opening produced by a debris flow appears on aerial photography.

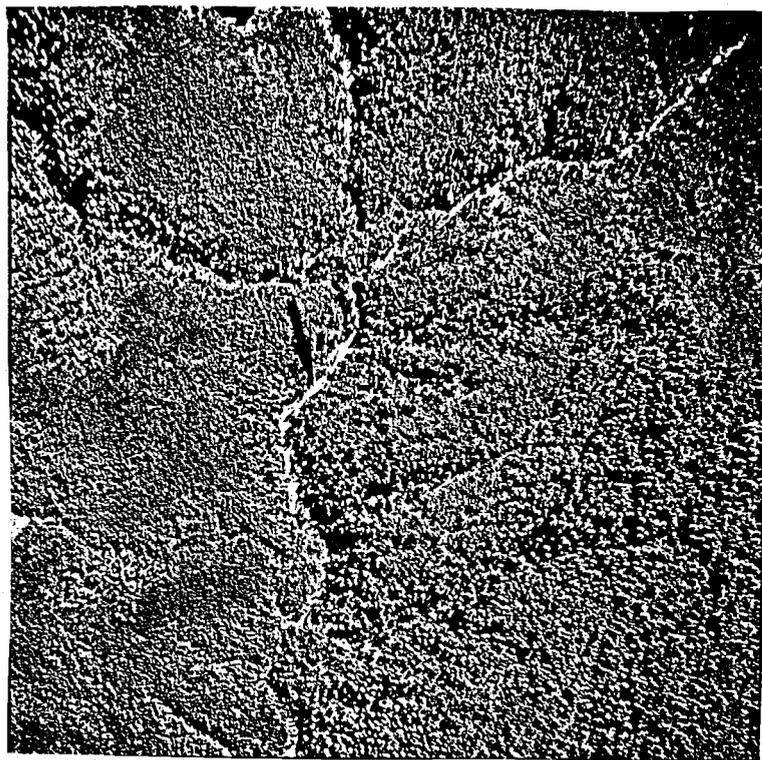


Figure 3. Example of how opening produced by peak flows and sediment transport appears on aerial photography.

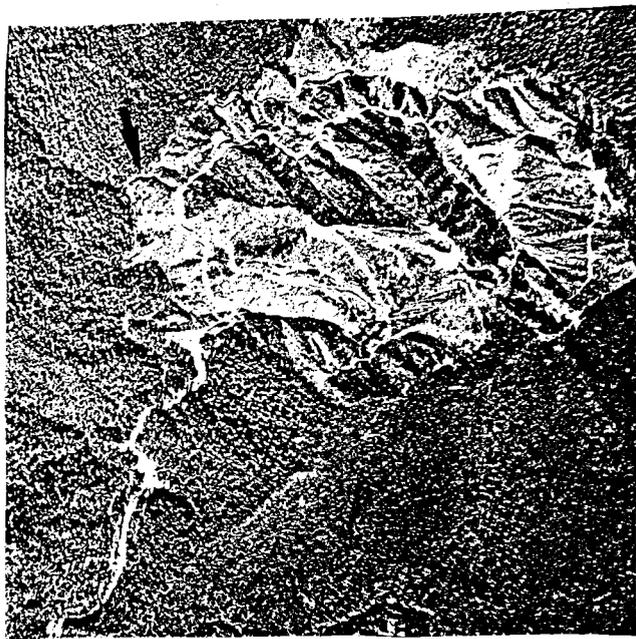


Figure 4. Example of how opening produced by surface erosion (dry ravel) appears on aerial photography.

channel produce characteristic channel responses, and (2) the pattern of channel response downstream is distinctive enough to be used as an indicator of the source of sediment. Studies in the Cascades show these assumptions to be valid (Grant et. al. 1984), though more strongly for landsliding and debris flows than for peak flows and surface erosion (Grant 1986).

The analysis of downstream effects was conducted in two parts, both of which use riparian canopy opening to interpret channel response to forestry practices (figure 5). While one part examines the sources and extent of opening in low order basins, the second part focuses on pattern of channel change on higher order channels. The linkages between the two are assessed by (1) examining the direct physical evidence of opening between upstream sources and downstream changes, and (2) the distribution and pattern of opening downstream in relation to basin harvesting levels when direct physical evidence is not apparent.

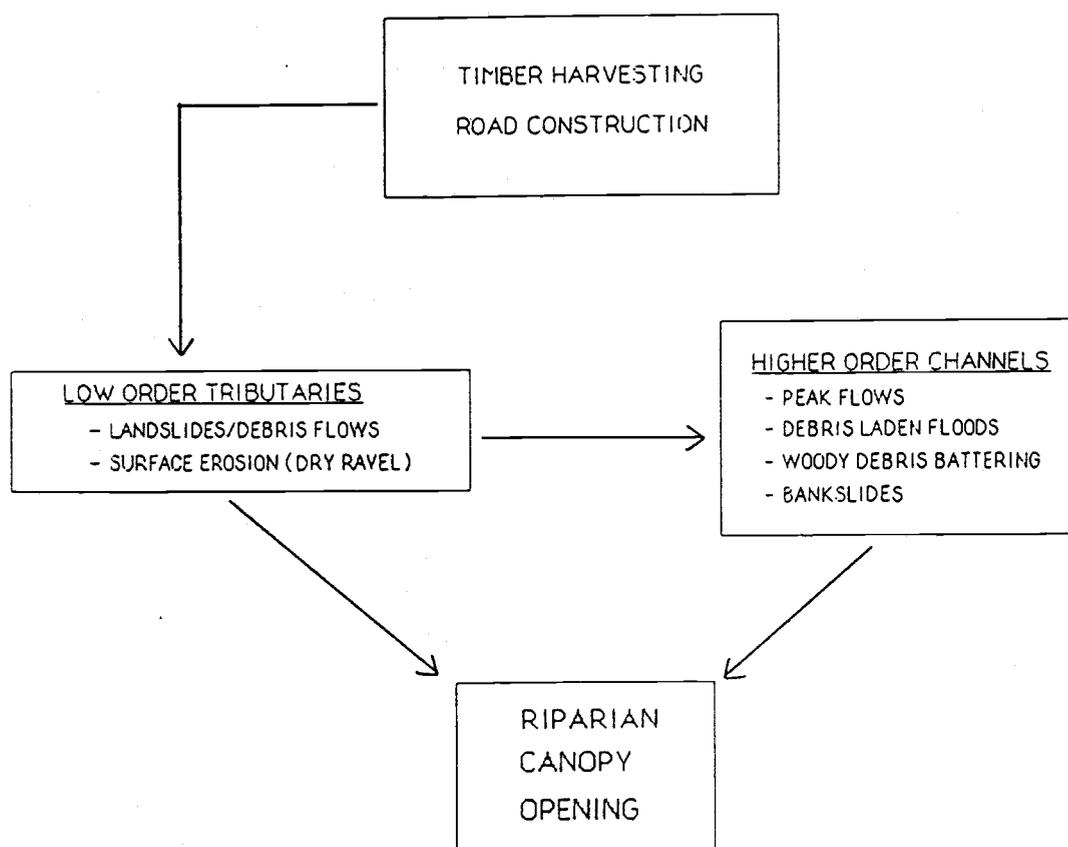


Figure 5. Study layout - Sediment impacts are identified by changes in riparian canopy opening in both low order tributaries and higher order channels. Physical linkages between upstream sources and downstream channel changes indicate presence of downstream effects.

PHYSICAL CHARACTERISTICS OF ELK RIVER BASIN

Location and Topography

Elk River Basin is a 200 square kilometer basin located in the Klamath Mountain province of southwestern Oregon, approximately 7 kilometers northeast of Port Orford (figure 6). The elevation ranges from 1340 meters at Iron Mountain to sea level at the mouth of the river. Landforms are steep and rugged, sculpted by fluvial and mass wasting processes. Razorback ridges and rocky bluffs are common with an average slopes of about 80%. Streams are generally deeply dissected, flowing through steep canyons, except where local conditions create alluvial flats.

The study site includes all the drainage area located above the junction of the main stem Elk River with Anvil Creek. Approximately 90% of this area is under management of the Siskiyou National Forest, Powers Ranger District; the rest is under private ownership, concentrated in the Bald Mountain area.

Geology and Geomorphic Processes

The Elk River Basin is underlain by the complex terrane of the Klamath Mountain province. The major geologic building processes include periods of sea floor subduction at the edge of the continent,

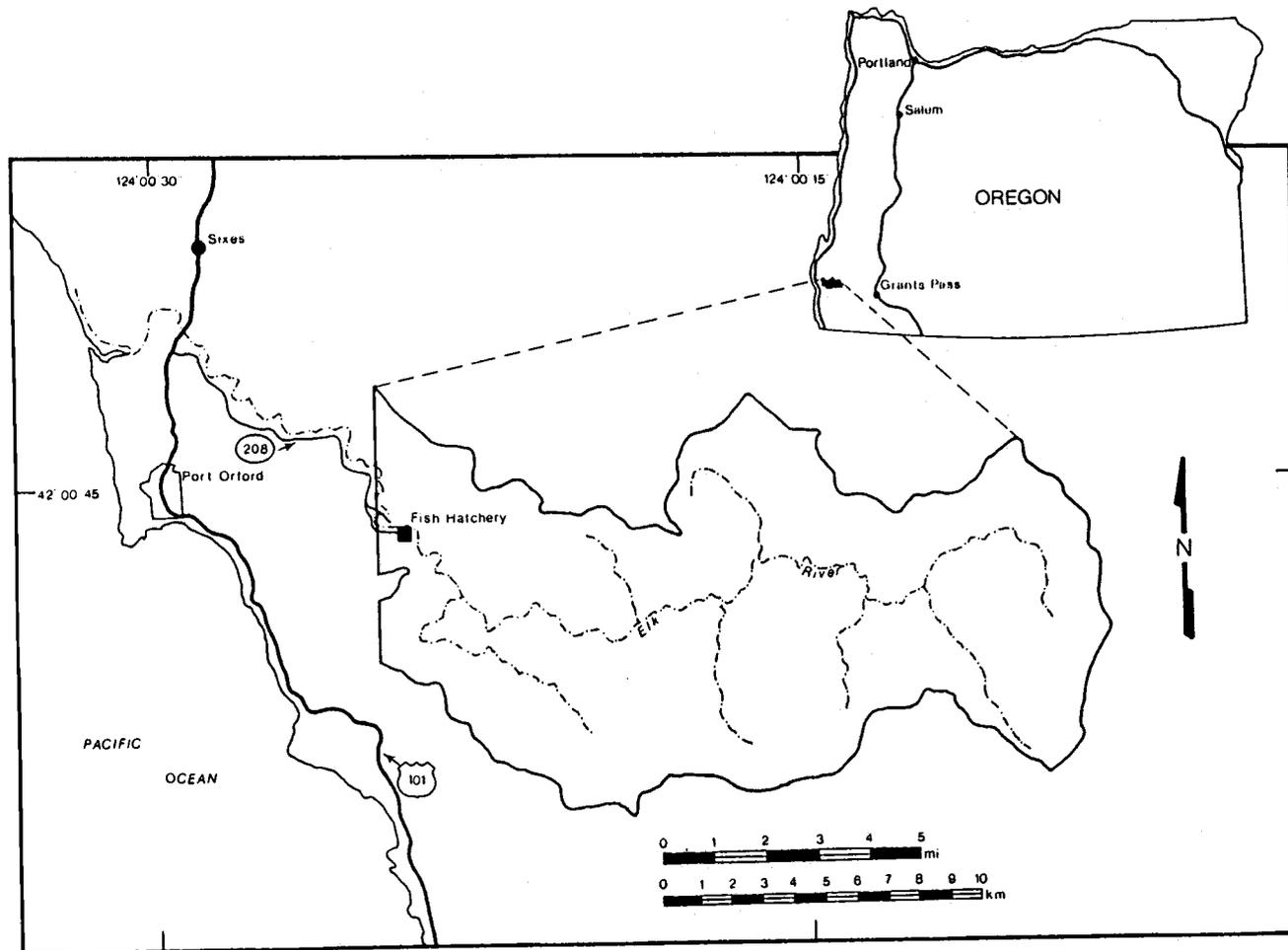


Figure 6. Location map of Elk River Basin.

volcanism and intrusion. As a result of this activity, the bedrock geology in the study area is diverse in lithology, consisting of metamorphic and igneous rocks of Jurassic age and sedimentary rocks of Cretaceous age (figure 7). Large scale folding and faulting occurs throughout the area and formations are often bounded by thrust and slip-strike faults. Additionally, the drainage network is largely controlled by the underlying geologic structure. The area appears to be tectonically active; recent periodic uplift is evidenced by elevated marine and fluvial terraces.

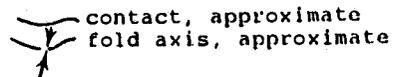
Much of the underlying lithology is erosive and highly unstable. Mass movements occur throughout the basin, though each lithology has inherently different failure types and rates. Although landsliding is common, debris flows are generally limited to areas underlain by quartz-diorite. Surface erosion, in the form of shallow landslides and dry ravel of stony soils, is generated from harvested areas underlain by Cretaceous sedimentary rock. Earthflows occur in areas of Jurassic metamorphic rock. Large scale banksliding occurs along stream channels at contacts between two lithologies of different competence. For a more detailed description of the geology and tectonic setting of Elk River Basin, see McHugh (1986).

Like most south coastal Oregon streams, Elk River is inherently sediment rich. Frissell (1986) estimated that sediment discharge in south coastal streams exceeds averages for northern and central coastal streams by one or two magnitudes. Karlin (1980) estimated the annual suspended sediment yield (bedload not considered) for Elk River to be approximately 350 tonnes/sq km-yr. This compares to an estimate

LEGEND

LOWER CRETACEOUS	Kr	Rocky Point Formation: graded sandstone and mudstone, pebble conglomerate	
	Kh	Humbug Mountain Conglomerate: coarse, massive conglomerate grading into coarse-grained sandstone	
	UNCONFORMITY		
UPPER JURASSIC	Jo Jv	Otter Point formation: mudstone, graded sandstone; (Jv) zones of volcanic flows, pyroclastics	
	UNCONFORMITY		
	Jg	Galice Formation: metamorphosed black, slaty mudstone and thin sandstone; hornfels near diorite contact	<div style="border: 1px solid black; padding: 2px; display: inline-block; width: 20px; height: 10px; text-align: center; line-height: 10px;">di</div>
	UNCONFORMITY		
	Jc	Colebrooke Schist: quartz-mica Phyllite, greenschist facies rocks, rare greenstone	<div style="border: 1px solid black; padding: 2px; display: inline-block; width: 20px; height: 10px; text-align: center; line-height: 10px;">Jur</div>
			ultramafic rocks: serpentine and peridotite
			diorite and related rocks: Quartz-diorite intrusion with associated mafic dikes

SYMBOLS



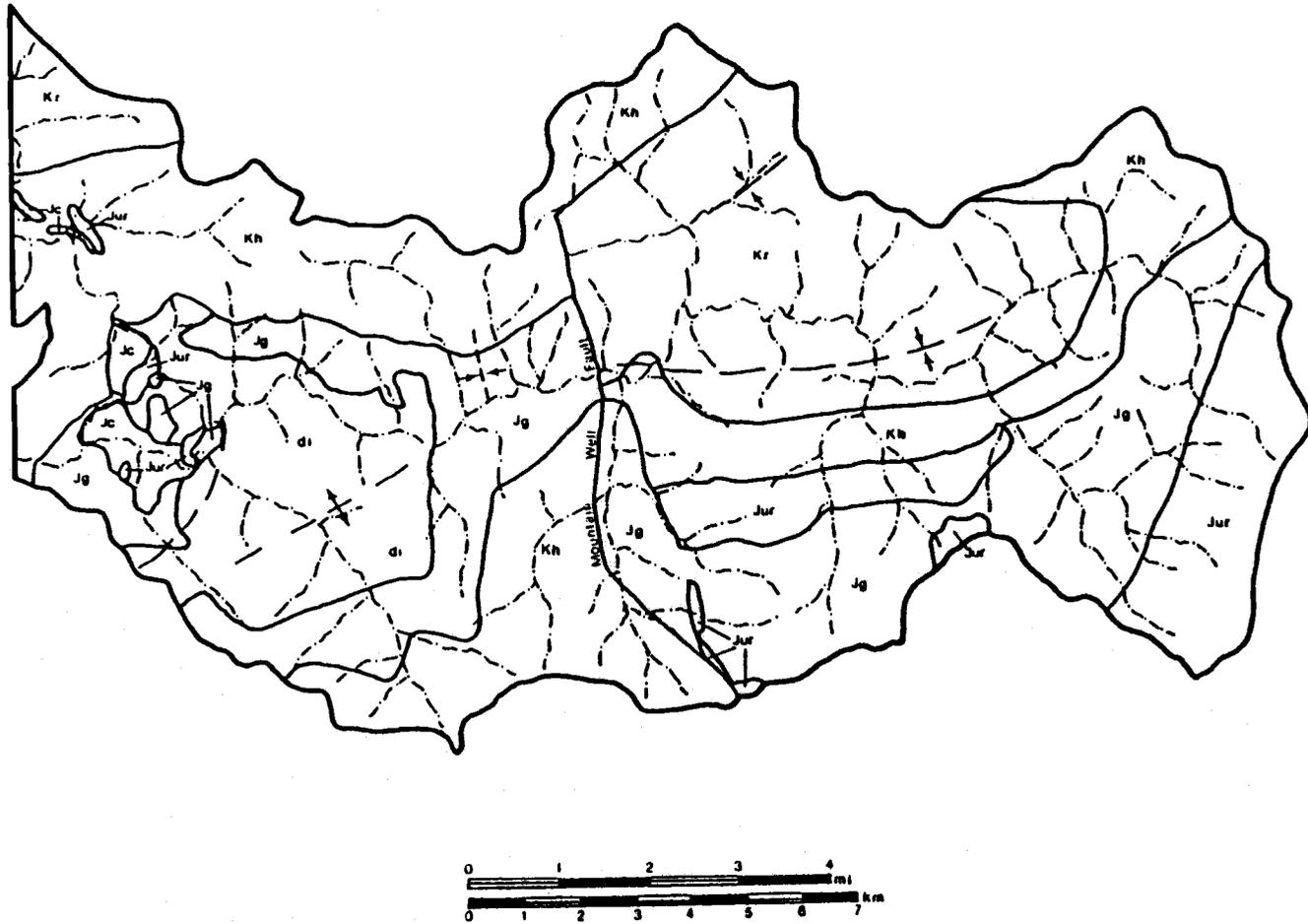


Figure 7. Geology map and legend, based on McHugh (1986).

of 125 tonnes/sq km-yr for central and northern coastal streams. High sediment discharges for Elk River Basin are attributed to steep river gradients and tectonically unstable formations common to the Klamath Mountain province.

Climate

A climagraph was constructed for a monitoring station located in Powers, OR., approximately 10 kilometers northeast of the study site (figure 8). The patterns depicted in the graph can be considered as representative of the climatic patterns in the study site, though the actual amounts of precipitation and temperatures ranges may vary.

The climate of the Elk River Basin is influenced by air masses moving inland off the Pacific Ocean. During the winter and fall, a low pressure cell originating from the north Pacific predominates over the area, producing a wet season from mid-October to mid-April. Ninety-five percent of the total yearly precipitation falls during these months. Storms tend to be of low intensity and long duration. Temperatures are mild and snow cover is rare, except at the highest elevations. Snow depth rarely exceeds 0.5 meters and usually melts by mid-spring.

During the summer months the low pressure cell which produces the wet winter weather gradually moves northward and is replaced by a high pressure system originating from the south Pacific. This air mass is warmer and drier and produces a dry season beginning in late spring and ending in early fall.

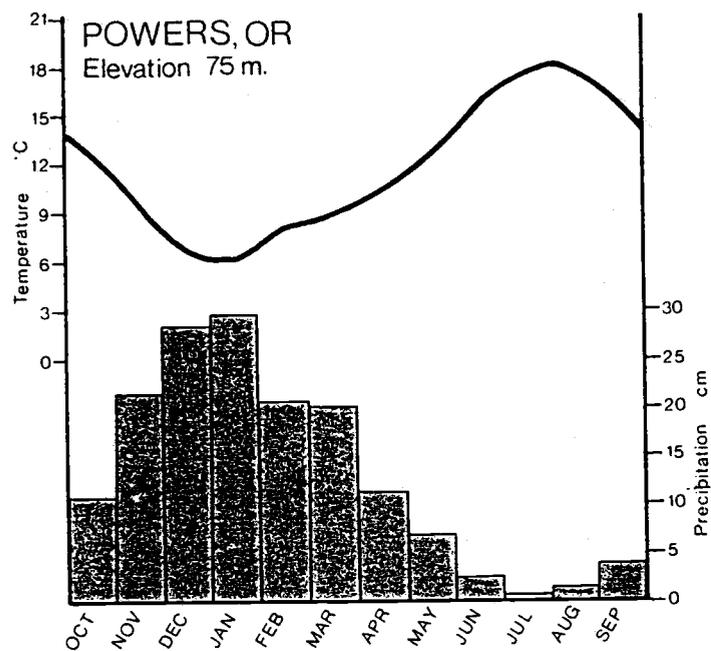


Figure 8. Climograph, Powers, OR. Based on thirty years of observation (1951-80). Source: National Climate Center.

The seasonal pattern of runoff typically follows the pattern of precipitation. This is due to relatively low infiltration rates into impermeable formations and soils, providing a minimum of retention. Snow melt, which would release a large amount of water to streams during the spring, is not an important influence. Peak runoff is due to heavy rains and occurs during the winter months (State Water Resources Board 1963). Extreme events are generally of short duration and are often preceded by prolonged wet periods. Saturated, antecedent conditions tend to increase the potential for landslide occurrence and episodes of landsliding generally occur during large storm events (Kelsey 1980, 1982). Significant peak flows occurred in the basin in 1944, 1955, 1964, 1971, and 1974 (table 2). The largest storm occurred in 1964-65 and has been cited as an example of a 100 year event (Waananen et. al. 1971).

Timber and Fisheries Resources

Elk River Basin has considerable timber and fisheries resources. The primary tree species found in the basin include Douglas Fir, Port Orford Cedar, Myrtlewood, western hemlock, tanoak, Western red cedar, sugar pine, grand fir, red alder, Pacific dogwood, white alder, madrone, and bigleaf maple (Meyer and Amaranthus 1979). The basin also provides excellent habitat for chinook salmon, steelhead trout, cutthroat trout, and coho salmon (Reeves, personal communication). Areas of high fish production (spawning and rearing sites) were noted on several tributaries to the Elk River, essentially coincident with

Table 2. Peak flows in South Fork Coquille River, Powers,
OR: 1944-80. Source: U.S.G.S. Water Data Reports.

YEAR	DATE	RETURN PERIOD (years)	DISCHARGE (cms)
1944	2-8	12	831
1950	10-28	4	732
1953	1-18	5	747
1953	11-22	5	735
1955	12-21	37	840
1955	12-26	7	756
1959	1-12	3	636
1964	12-22	80-150	1467
1965	1-19	2	618
1966	1-3	6	750
1966	1-6	4	720
1966	3-8	3	627
1969	12-21	2	621
1971	1-16	18	834
1972	1-21	3	663
1974	1-15	9	768

the distribution of discontinuous floodplains (Figure 9). Elk River is also the site of a Oregon Department of Fisheries and Wildlife fish hatchery, located on the main stem Elk River near the junction of Anvil Creek.

Management History

Management activity prior to 1956 was minimal and confined mainly to private lands in the Bear Creek basin, a tributary to Bald Mountain Creek. By 1956, this area was heavily roaded and completely denuded of vegetation. Between 1956 and 1964, Panther, Butler, and Purple Mountain Creeks were roaded and clearcut utilizing techniques which caused severe environmental disturbance, including construction of logging roads in the stream channel and removal of timber from the entire hillslope. Since the mid 1960's, less severe management techniques have been employed in the basin; more roads were located along ridgetops, the size of clearcuts decreased, and buffer strips were used to protect the stream channels. By 1979, all basins in the study (except Red Cedar Creek) had some degree of management activity (Figure 10). Though the rate of timber harvesting had slowed by the late 1960's, areas accessed since then were increasingly steep and unstable. No notable decline in landslide frequency was noted by McHugh (1986) as a result of improved management techniques.

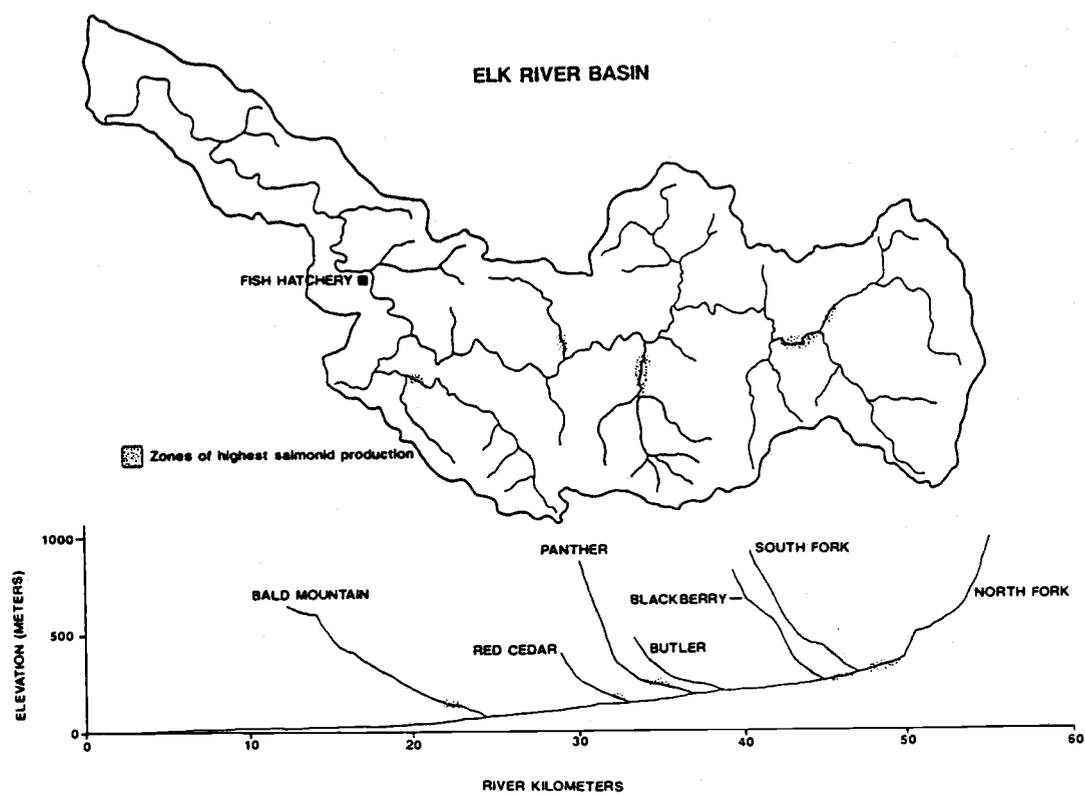


Figure 9. Zones of highest salmonid production, from Reeves et. al. in progress.

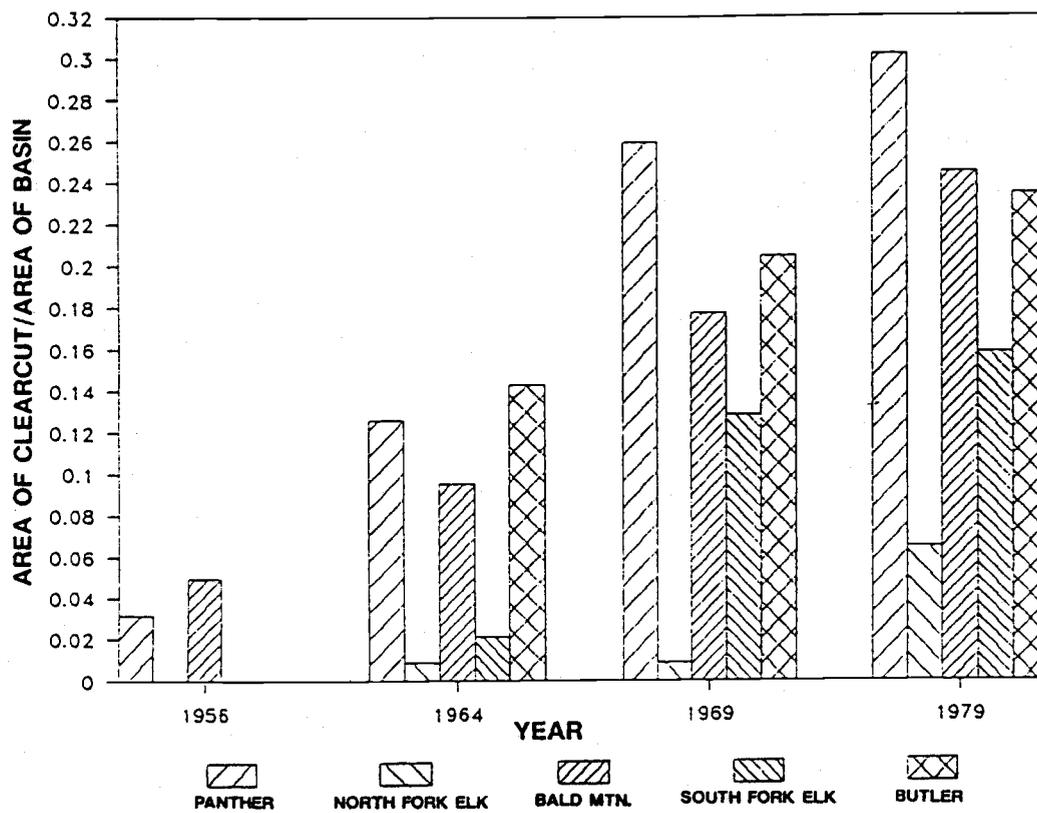


Figure 10. Timing and amount of harvesting in six basins inventoried.

METHODS

The drainage network in the Elk River Basin was identified using contour crenulations on 1:24,000 scale topographic maps, aerial photography, Siskiyou National Forest Total Resource Inventory (TRI) aquatic habitat maps, and, in some areas, field checking. All channels included in the network were assumed to be of sufficient size to carry water at yearly high flows. Once the network was identified, a Horton-Strahler (Strahler, 1952) analysis was performed to determine stream order. All stream segments were assigned an identification number based on order and location within the sub-basin for use in analysis.

Six tributaries to the Elk River were chosen for this study based on stream size (fourth order or larger) and significance of the stream for anadromous fish habitat as determined by Reeves et al. (in progress) (Figure 11). Five of the basins were logged to varying degrees. Red Cedar Creek was included in the study as a geomorphic benchmark, since it is part of a wilderness area and has never been logged. It is considerably smaller in drainage area than the other basins.

Areas of clearcuts and lengths of roads were digitized from the Siskiyou National Forest TRI maps (1:15,840). The year clearcuts and roads were first generated was noted and summarized by photo interval for inclusion in the database. The information was compiled for each sub-basin as well as for the entire Elk River Basin.

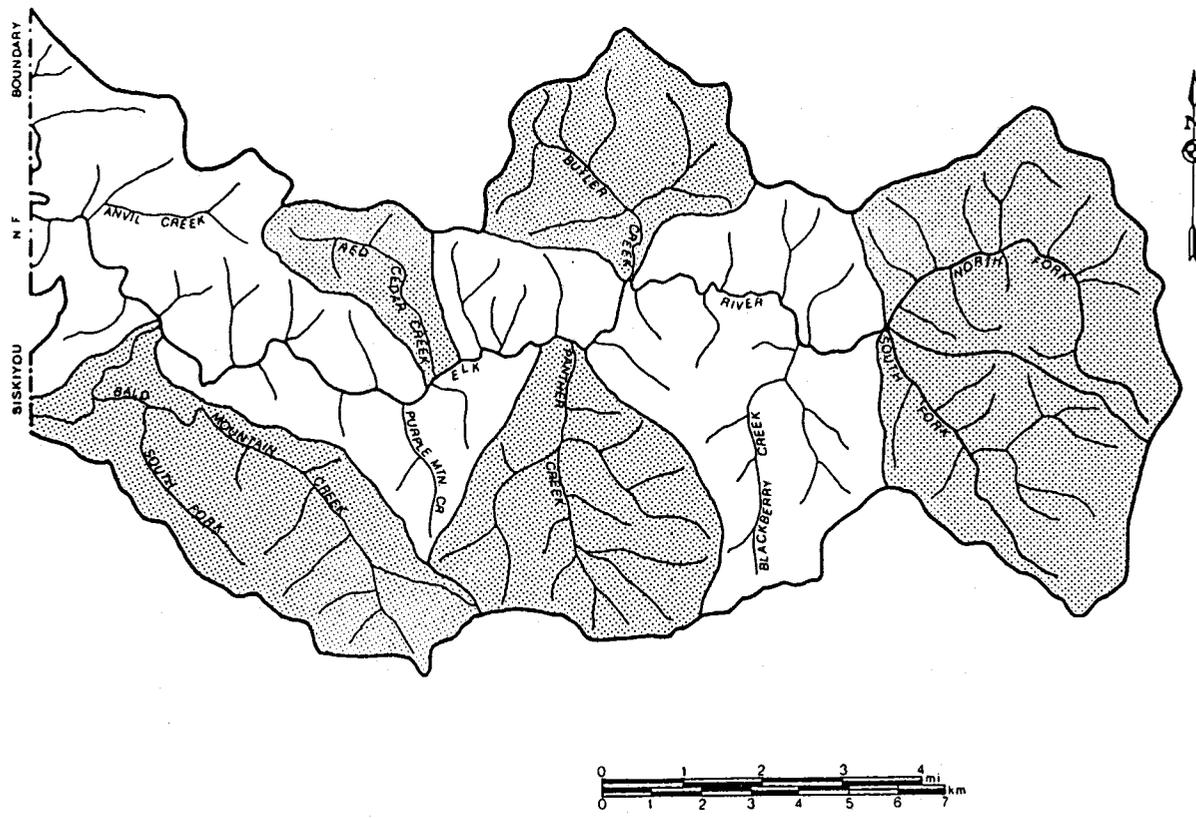


Figure 11. Stipple area indicates basins inventoried using air photo interpretation.

Air Photo Investigation

The use of air photos provides a relatively quick and inexpensive method for historical reconstruction of channel conditions over large, forested drainage basins. Aerial photographs taken in 1956, 1964, 1969, and 1979 were used to identify sources of sediment and changes in channel condition. The 1956 (1:12,000, black & white) photos provided a picture of channel conditions prior to extensive management entry in the basin. The 1964 (1:12,000, black & white) photos were taken the summer before the 1964 event and depict pre-storm conditions existing in the basin. The 1969 (1:15,840, black & white) photos were the earliest post-storm photos available and were used to estimate how much change was produced by the 100-year event in 1964. The most recent photos available, taken in 1979 (1:24,000, color) were used to determine if the channels had recovered from the effects of the 1964 storm. Air photos taken in 1940 and 1986 were also examined for a qualitative assessment of the channel conditions, but were not included in the inventory.

Photographs were viewed using a mirrored stereoscope with a magnification of 2x - 4x. All photo work was done under stereo to more accurately define the channel boundaries and overcome shadow effects. Interpretation was limited to the central portion of the photographs to minimize the effects of edge distortion. Distances were measured using a photo scale marked on a clear mylar strip and a graduated eye loop with a scale marked in tenths of millimeters.

Open reaches were classified by whether opening began at a

landslide or ravel slope, or in forest, clearcut or road with no landslide. Distance measurement began at the initial site of opening and moved down channel until the order of the segment changed or the main stem of the Elk River was reached. Widths of opening were sampled at 100 meter intervals, beginning at the upstream end of an opening and stopping at the downstream end of the same opening. Unopened reaches downstream from the initial opening had no width measurement, but lengths of these reaches were included in the total measure of channel length. The location of landslides, tributary junctions, road crossings, clearcuts, and other influences along the channel were noted during data collection. This information was entered onto a primary data collection form, found in Grant 1988.

Distances between two known points were compared between photo years as a check on accuracy. A ten percent difference was allowed for photo measurement error. When more than ten percent error was encountered, the segments were remeasured until a more acceptable measurement was obtained. Length and location of openings were mapped on clear mylar over the TRI base map at a scale of (1:15,840) for a visual comparison of change in canopy opening relative to the location of roads and clearcuts.

Sediment impacts on the main stem of Elk River were assessed using air photos by counting the number of gravel bars in the main channel segment. This was done for six photo series (1940, 1956, 1964, 1969, 1979, 1986). All lateral and mid-channel bars located in the unvegetated, active channel were included in the tally. The change in the number of gravel bars over time was used as a surrogate

measure of sedimentation impacts, assuming that an increase in the number of bars indicated an increase in sediment in the channel. All photos were taken in the summer and the discharge at the time of the photos was comparable.

Field Investigation

A field investigation was conducted on three tributaries to the Elk River: Panther Creek, Red Cedar Creek, and North Fork Elk River. These tributaries were chosen because each contains an alluvial area and was described by Reeves (personal communication) as having significant concentrations of anadromous fish. The purpose of this investigation was to measure and characterize the morphology of these highly productive areas.

Data collection techniques used were based on Grant's (1986) characterization of stream channel units and valley floor surfaces. Distances were measured using a thirty meter tape and elevations were measured using a hand-held level and nine meter fiberglass rod. Data collected on these tributaries included the width of (1) the valley floor, defined as the distance spanned by surfaces less than 3 meters in height, (2) the active channel surface, estimated by the width of the unvegetated channel, and (3) the wetted surface or the width of the channel at summer low flow. A three meter vertical cutoff was used to define the limit of the valley floor, assuming that most flows would not exceed this level. Valley floor width was measured at 100 meter intervals, beginning at the mouth of the channel. Longitudinal

profile data for the stream was collected by measuring the length and elevation gain between breaks in the bed slope. Both valley floor and longitudinal profile information were used to quantitatively define portions of the channel which would be most prone to sedimentation impacts due to low slopes and wide valley floors.

RESULTS

CHAPTER 1.

OVERALL PATTERN OF OPENING IN ELK RIVER BASIN

Open canopies were not limited to timber harvesting impacts, since they occurred in both logged and unlogged basins. Early in the study period, prior to road construction and logging, opening was evident in three of ten tributaries to Elk River. As time progressed and more of the basins were logged, the likelihood of a channel exhibiting opening increased. By 1969, nine of the basins had been harvested to some degree and all but one exhibited opening in the riparian corridor. Tributaries were considered open if any portion of the channel exhibited unvegetated reaches, regardless of location or the processes which created them (table 3).

Though the presence or absence of opening is not limited to harvested basins, there appears to be a moderately strong correlation between amount of harvested area in a basin and the extent of opening in the channels draining that basin ($r^2=.63$) (figure 12). This relationship is likely a result of the close spatial association between open canopies and harvested units. New opening was produced on-site where harvested units encompassed the stream channel and landslides and surface erosion produced visible channel change. In contrast, off-site opening was only locally important and did not

Table 3. Presence or absence of opening and forestry activity in ten tributaries to Elk River.

TRIBUTARY TO ELK RIVER	ORDER	sq km AREA	-----1956-----		-----1964-----		-----1969-----	
			OPEN	MANAGEMENT	OPEN	MANAGEMENT	OPEN	MANAGEMENT
SOUTH FORK	4	19.35	Y	N	Y	Y	Y	Y
NORTH FORK	4	24.50	Y	N	Y	Y	Y	Y
BULTER	5	18.00	N	N	Y	Y	Y	Y
BLACKBERRY	3	12.45	C	N	C	Y	C	Y
MILBURY	3	2.50	C	N	C	Y	Y	Y
PANTHER	5	23.60	Y	Y	Y	Y	Y	Y
RED CEDAR	4	7.65	Y	N	Y	N	Y	N
BALD MOUNTAIN	4	27.60	Y	Y	Y	Y	Y	Y
ANVIL	3	7.14	Y	Y	Y	Y	Y	Y
PURPLE MOUNTAIN	3	4.02	C	N	Y	Y	Y	Y

Y= YES

N= NONE

C= LANDSLIDE SCARS PRESENT BUT NO OPENING IN CHANNELS

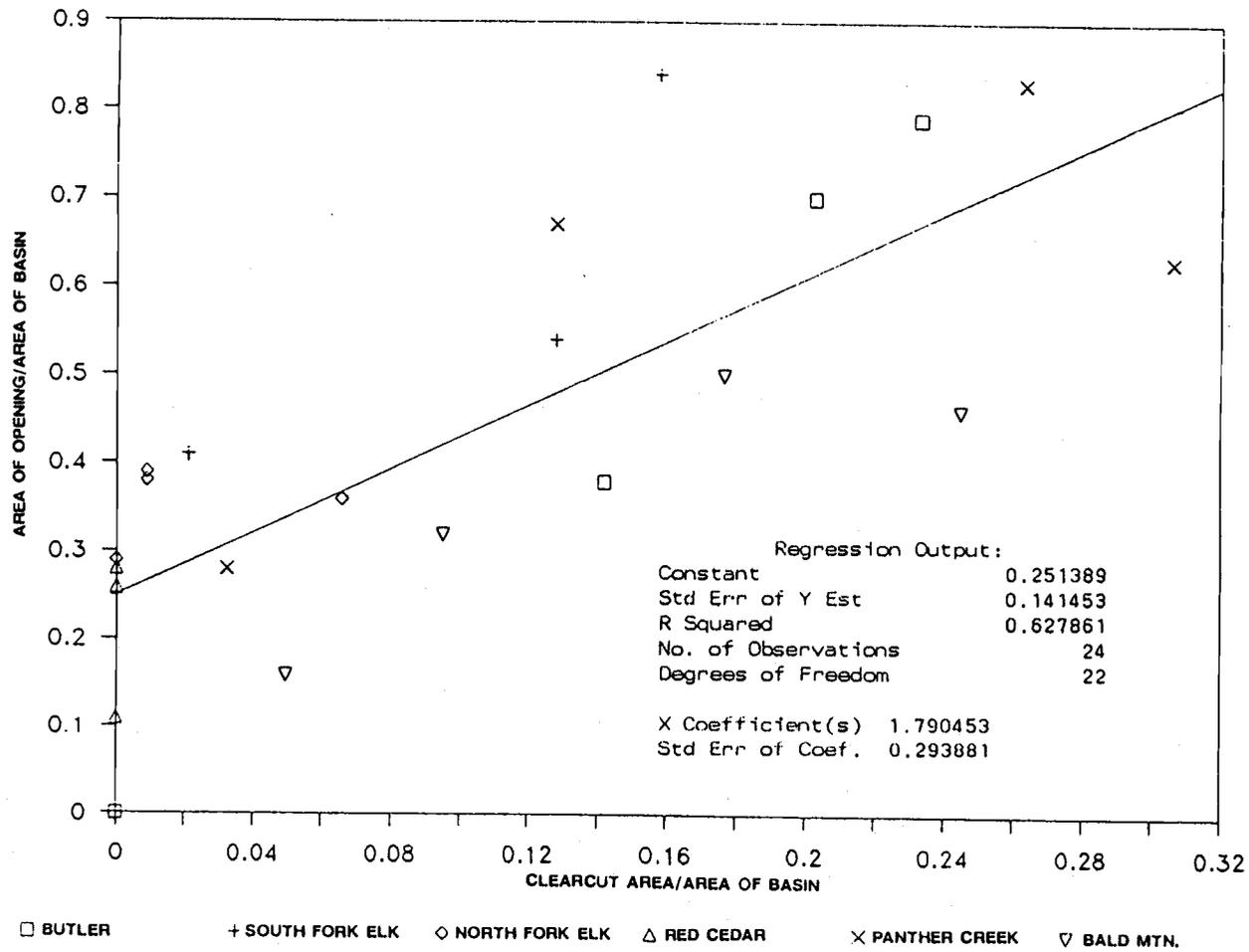


Figure 12. Relationship between area of clearcuts and area of open canopies relative to basin size on four photo series sampled.

contribute much to the total opening. As a result, opening increased somewhat proportionally to the area of harvested basin. Variability in this relationship is attributed to differences in hillslope processes reflecting a heterogeneous geology and differences in the inherent channel sensitivity to sediment input (discussed in Chapters 2 and 3 respectively).

While opening in Elk River Basin increased during the study period, the distribution of opening was not uniform over the area (figure 13). Early in the study, opening was limited to fourth and fifth order channels. Later, the distribution of opening followed the distribution of management activity; clearcutting and road construction was concentrated along ridges and mid-slopes, for the most part, and avoided higher order channels. As a result, new opening occurred mainly in low order basins. The largest increase in opening in low order channels occurred between 1964 and 1969 and is likely the result of the 1964 storm; McHugh (1986) documented an increase in landsliding attributed to this storm, hence, an increase in opening in low order channels is also attributed to this event.

On the other hand, opening on the main channels of the tributary basins did not change appreciably during the study period (figure 14). Generally, the total length of stream channel either open or closed remained consistent between photo years, ranging from twenty to twenty-seven percent of the total channel length in open condition and forty-seven to fifty-three percent of the total channel length in closed condition. The amount of new opening and canopy closure comprised only a small component of the total channel length - less

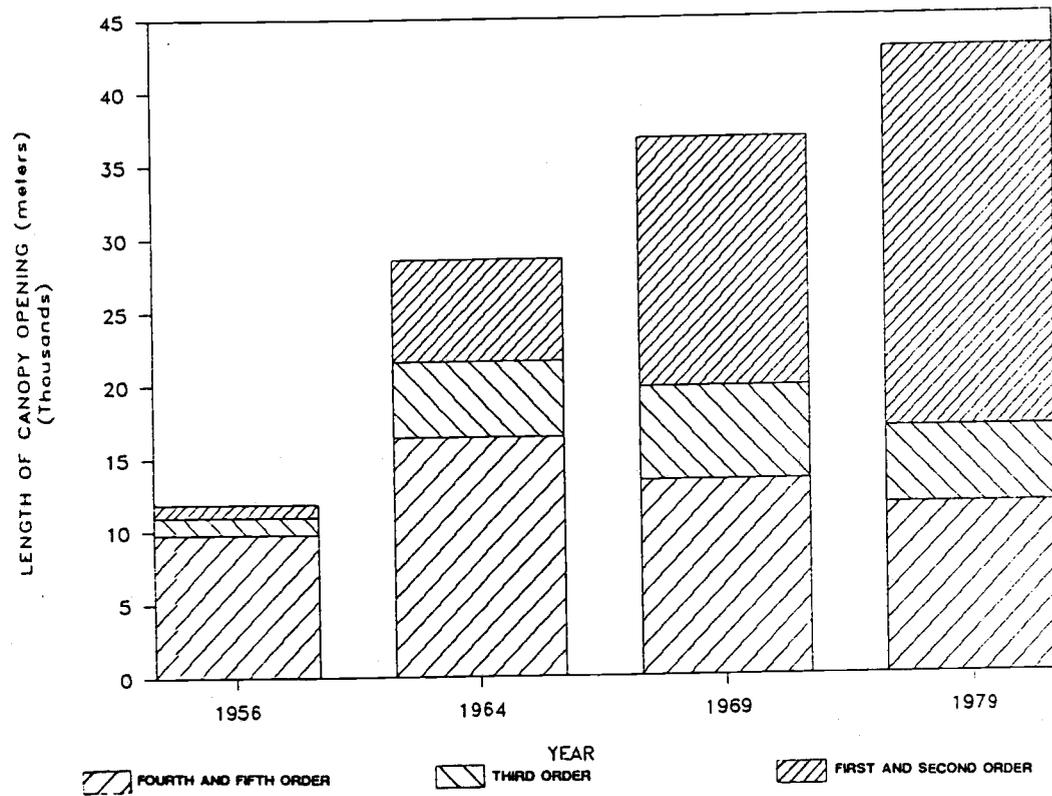


Figure 13. Total length of open channel by order and by photo series.

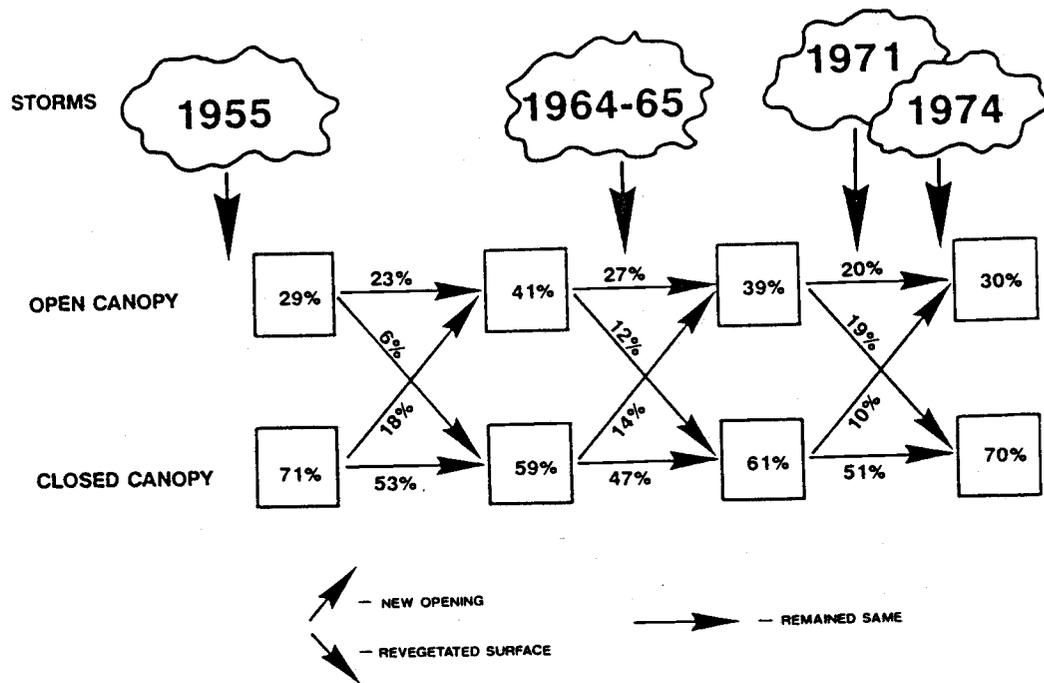


Figure 14. Synopsis of change in percent of channel length exhibiting open and closed canopies over time on main channel of all basins inventoried.

than twenty percent.

The largest increase in new opening on the main channels occurred between 1956 and 1964 (eighteen percent of the total channel length opened). However, no major storm occurred during this photo interval, suggesting that opening was due to some cause other than high peak flows. Lag effects from an earlier (1955) storm may be partly responsible for the increase in lengths of open channels at this time. These effects occur when the initial event deposits sediment and wood in channels which is later remobilized during a more moderate event, such as in 1959 (three year return interval). The subsequent transport of material may produce appreciably more channel change during the low magnitude event than would have occurred otherwise.

On the other hand, the high magnitude event in the 1964-69 photo interval did not produce substantial new opening (fourteen percent), even though it was significantly larger than other storms in the study period (100 year return interval). Channels may have been altered to such an extent during the 1955 event that additional impacts attributable to the 1964 were not evident in most channels. Given this sequence of events and amount of opening, it is suggested that channel response to a moderate or large storm cannot be considered independent of channel condition prior to the storm occurrence; storm sequence is as important as magnitude in producing channel changes (Beven 1981). By 1979, opening on main stem channels declined to approximately the same level as 1956, indicating there was little net change in opening in this portion of the basin.

CHAPTER 2.

LANDSLIDING AND CANOPY OPENING IN LOW ORDER BASINS

Landsliding and surface erosion are natural and common occurrences in steepland areas. However, the natural instability which makes these areas prone to failure may be amplified when changes in hillslope cover and contour are produced by harvesting and road construction. In an Elk/Sixes landslide inventory, timber harvesting increased the failure rate 7 times over the natural forest rate while roads were responsible for rates 48 times the unmanaged rate (McHugh, 1986).

Rates of sediment delivery, however, were not uniform over the basin. Differences in rate and type of delivery were associated with the variation in the inherent stability of the geologic terranes. Areas underlain by quartz-diorite had the highest rate of landsliding for both roads and clearcuts (108 times and 19 times the natural forest rate). Failure rates in the sedimentary and metamorphic rock were comparable and were about one-third the rates in the diorite (table 4). While no rates for surface erosion were available, extensive dry ravel was apparent in harvested areas underlain by Cretaceous sedimentary rock, a more competent lithology in comparison with others in the study site.

Table 4. Failure rate in Elk and Sixes basins by terrane and management influences (from McHugh 1986).

		Unmanaged	Harvested	Roaded
Metamorphic Jg, Jc, Jur	Failure rate (events/(ha*yr)*1000)	0.08	0.49	2.29
	Relative rate (compared to unmanaged)	1x	6x	27x
		Unmanaged	Harvested	Roaded
Sedimentary Kh, Kr	Failure rate (events/(ha*yr)*1000)	0.08	0.44	3.35
	Relative rate (compared to unmanaged)	1x	5x	41x
		Unmanaged	Harvested	Roaded
Intrusive di	Failure rate (events/(ha*yr)*1000)	0.04	0.74	4.32
	Relative rate (compared to unmanaged)	1x	19x	108x
		Unmanaged	Harvested	Roaded
All Rock Types	Failure rate (events/(ha*yr)*1000)	0.06	0.45	2.94
	Relative rate (compared to unmanaged)	1x	7x	48x

Processes of Canopy Opening in Low Order Tributaries

One of the direct results of this increase in sediment delivery was an increase in opening of the canopy cover in low order basins. Both landslides and surface erosion created opening; variables which influence the extent of opening created include the size and location of sediment input in relation to the channel, speed at which it enters the channel, composition of the material involved, and the timing of the input relative to large storms.

Landslides dump a pulse of sediment and debris directly into channels at a rapid rate. This material may either stop shortly after entering the channel or continue down the network, creating a debris flow - the channelized transport of a high velocity slurry composed of sediment, water, and organic debris (Varnes 1978, Swanston and Swanson 1976). The transition between landslides and debris flows occurs when sufficient water exists to liquefy the landslide mass, most commonly during large storms. The abrupt input of material along with the shear stresses associated with movement of material downhill may uproot trees and soil material, incorporate them into the mass, and produce an opening of the riparian canopy cover.

As the mass continues to move, erosion of unstable banks, toeslopes, and channel beds occurs, adding more material to the flow and extending the effects of the landslide away from the initial site of disturbance. When the material reaches a higher order channel, a change in rheology may occur due to an additional increase in water in

the mass. The debris flow is transformed into a debris-laden flood and may continue the destructive pattern several kilometers downstream. Material is deposited where site conditions are no longer conducive to movement of the mass.

Several factors influence whether or not a debris flow is generated from a landslide, most importantly network and channel geometry (gradient, width, abrupt changes in channel direction) (Benda 1985) and properties of the flow (water content, mobility, character of movement, size of debris) (Swanston and Swanson 1976, Swanson and Lienkaemper 1978). Longer debris flow runouts are expected in steep, narrow channels where the angle at tributary junctions is small. Shorter runouts are expected where tributary angles are close to perpendicular (figure 15). In addition, areas underlain by less competent lithologies are likely to exhibit debris flows, especially where soils are non-cohesive and have high permeability (Meyer and Amaranthus 1979).

Surface erosion was also associated with open canopies, though the processes which created the response were different from landsliding. Dry ravel and small, shallow hillslope failures are the most common type of surface erosion which produced opening. Sediment delivery, though not abrupt, is generally persistent over a number of years. This is primarily due to the characteristically slow revegetation of slopes with active dry ravel; vegetation establishment is limited due to the continual sloughing of material from harvested hillslopes producing an unstable substrate. Several areas remained bare over twenty years after the initial harvesting.

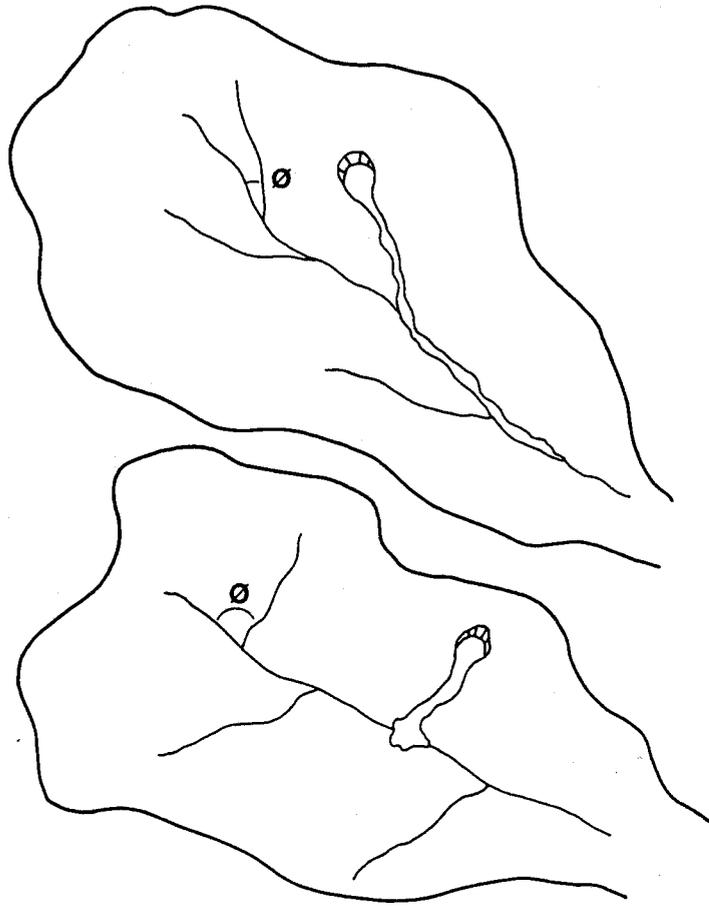


Figure 15. Role of tributary junctions in controlling runout distance of debris flows.

As sediment is continually deposited in the channel by dry ravel, water depth decreases and flows may go subsurface. The ability of the channel to transport sediment is reduced and additional sediment accumulates, producing local channel widening and an open canopy signature on air photographs. The deposited material may eventually be transported downstream, usually during high magnitude storms, with potential channel widening and opening occurring in higher order channels.

Role of Landslides and Surface Erosion in Generating Downstream Effects

Though both landslides and surface erosion produce opening in Elk River Basin, landsliding was the most common initiator of canopy opening (figure 16). An analysis of initial sites of opening on the 1969, post-storm photos shows that seventy-four percent of all openings were initiated by landslides - both axial (parallel to the channel) and riparian (perpendicular to the channel) - while only twenty percent of the openings were associated with surface erosion and dry ravel. The preponderance of initiation sites generated by landslides as opposed to surface erosion was attributed to the effectiveness of landslides at producing opening, since the direct impact of moving mass is involved; not all dry ravel sources produced a detectable response in the channel.

Most of the openings in low order tributaries were associated with harvest activity in a basin. Seventy-two percent of the landslides and all of the dry ravel sites initiated in managed units.

Classification of Initial Sites of Disturbance, 1969

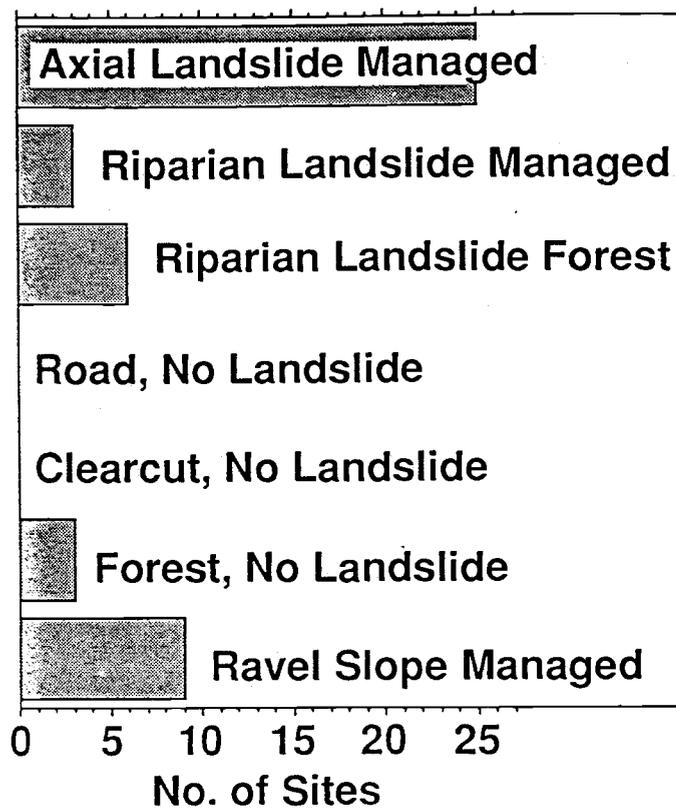


Figure 16. Distribution of opening by type of disturbance at initial site of opening on 1969 photo series.

Fifty-five percent of the landslides were from clearcuts while sixty-three percent were from roads; forty-eight percent of the sites were attributed to both influences.

Though landslides were the most common source of sediment delivered to stream channels, most landslides in Elk River Basin were not associated with extensive lengths of opening. The average length of open channels from all landslides which entered first and second order basins was about 240 meters, with the longest response measured at 1174 meters (figure 17); most produced openings in the 150 - 250 meter range.

In contrast, a similar study carried out in the Western Cascades showed the average length of opening from landslides was 429 meters, with the longest continuous opening measuring over 2800 meters long (Grant 1986). In the Knowles Creek Basin of the Oregon Coast Range, seventy-four percent of the landslides produced debris flows which traveled over 400 meters, with some extending over 1600 meters (Benda 1985). The differences in the length of channels opened in these studies indicates that landslides in Elk River Basin do not generate extensive debris flows in comparison with other areas. The implications of this finding are vital to the question of what mechanisms are active in producing downstream effects.

Neither the drainage pattern or underlying terranes in Elk River Basin is conducive to long debris flow runout, with exceptions noted locally. Network and channel geometries vary considerably in Elk River Basin, largely influenced by lithology and geologic structure. Tributary angles range from approximately twenty to thirty degrees in

Lengths of Open Canopy Reaches Generated by Landslides on First and Second Order Channels

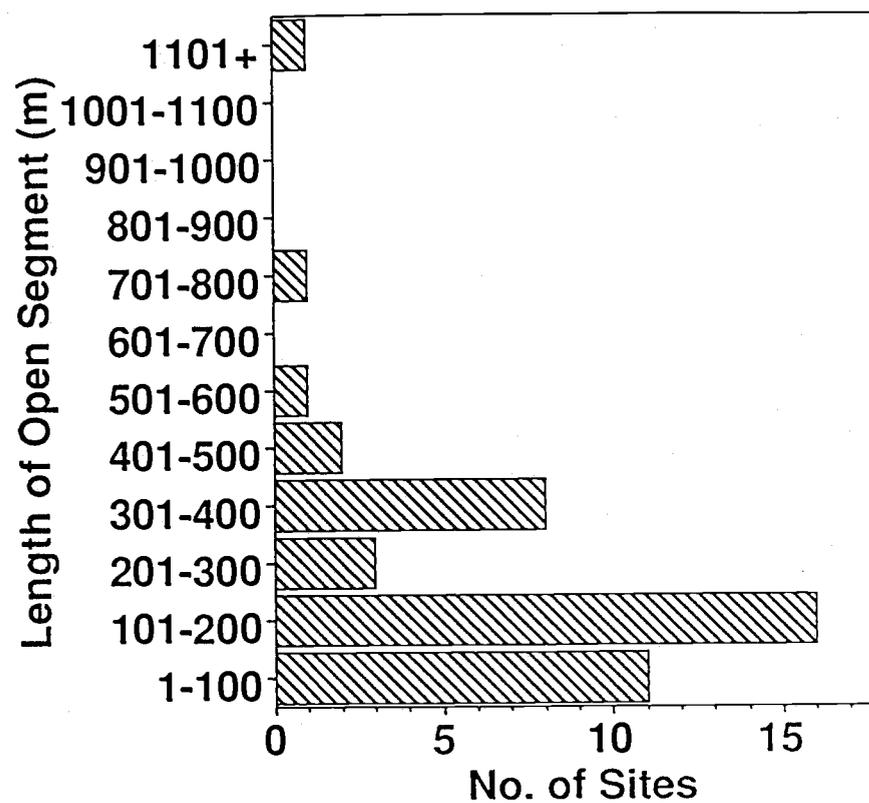


Figure 17. Frequency distribution of lengths of open canopies initiated by landslides entering first and second order channels.

areas underlain by the Humbug Mountain formation to ninety degrees in the quartz-diorite areas. Though tributary angles are small in the Humbug Mountain formation and the potential for long runouts is high, the erosional processes in this terrane are not conducive to the formation of debris flows. Landslides are shallow, with small or nonexistent headscarps; chronic dry ravel of harvested slopes is common. It appears that debris flows don't form where the erosional processes do not generate a coherent mass, but rather slip or break up into smaller parts.

On the other end of the spectrum, the most extensive openings were generated in areas underlain by quartz-diorite and parts of the Galice formation in Bald Mountain Creek. Though tributary angles were nearly perpendicular, debris flows created openings greater than 300 meters in length - the most extensive in the basin. Had the tributary angles been smaller, the runouts would likely have been longer. The lithology was conducive to debris flows, but the length of runout was limited by changes in channel direction as indicated by debris flows stopping at tributary junctions.

As a result of both the erosional processes and character of the drainage network in Elk River Basin, landslides from low order basins did not directly impact higher order channels downstream, except locally. An analysis was conducted which noted the order where an individual landslide initiated and the order where the landslide or resultant debris flow stopped, as interpreted by the point where continuous opening stopped (figure 18). Using this information, a conceptual model was developed to estimate the number landslides in

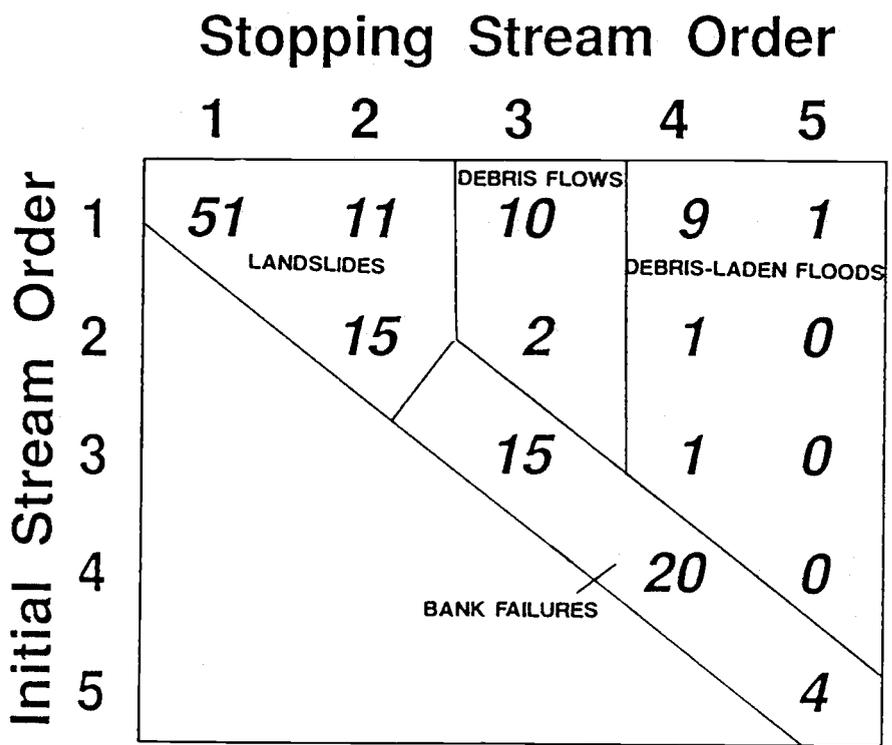


Figure 18. Landslide Matrix - Conceptual model of types of debris movement in Elk River Basin. Matrix depicts orders on which continuously open reaches begin and end on. Model uses potential water content of debris mass to define boundaries between types of debris movement.

Elk River Basin which generated debris flows and debris-laden floods.

The model was based on the potential water content of a debris mass, as determined by the stream order the opening ended on and assuming water content increases as higher order channels are encountered. For example, if a landslide was generated on a first or second order channel and ended on a first or second order, it is likely the movement was low in water content and did not generate a true debris flow. On the other end of the spectrum, if a landslide generated on a low order channel reached a fourth or fifth order channel, then the movement was likely high in water content and may have formed a debris-laden flood, with a higher potential for movement and opening down channel. While a continuum between flow types is recognized and the boundaries established are not firm, the model does provide a means of determining the frequency of debris flows compared to other types of debris movement; ideally, field examination of debris deposits should be conducted to determine the true character of the flow (Costa 1974).

Of the 100 landslides inventoried between 1956-1979 which generated opening on first and second order channels, seventy-seven percent ended on first or second order channels. The other twenty-three percent eventually reached third order or larger channels and were classified as debris flows or debris-laden floods. The largest portion of the debris flows or floods occurred in Bald Mountain Creek (seventeen of twenty-three) in areas underlain by quartz-diorite and the Galice formation. Though eleven percent of the debris movements were classified as potential debris-laden floods,

most produced actual openings less than 100 meters in length on higher order channels.

Given that most landslides did not generate debris flows which directly impacted higher order channels, downstream channel changes could not be spatially linked to upslope disturbances. Other methods of assessing whether the opening observed in higher order channel was due to increased sediment delivery from harvested areas are needed. In particular, the pattern of opening in downstream reaches over time relative to large storms and management history can be used to document cumulative or downstream effects.

CHAPTER 3.

OPEN CANOPIES IN FOURTH TO FIFTH ORDER CHANNELS

Open canopies occurred in some fourth to fifth order channels throughout the study period, specifically in the lower portions of Panther and Red Cedar Creeks and the North and South Forks Elk River.

Opening was not uniformly distributed over these channels, but occurred in distinctive zones, characterized by wide valley floors and low channel gradients. McHugh (1986) noted the distribution of these zones coincided with geologic controls such as faults, synclines, and differences in competence between formations, indicating that the morphology of these stream segments is persistent as is the potential for opening and sediment impacts.

The Role of Channel Morphology in Promoting Sediment Deposition and Open Canopies

The potential for sediment deposition is relatively high in wide, flat reaches due to a deceleration of flows and a decline in shear stress associated with channel widening and low stream gradients (Bull 1979). Channel shear stress and discharge equations show how these relationships work:

$$\tau = \gamma R S$$

$$Q = VRW$$

substituting for R in these equations:

$$\tau_c = \frac{\gamma QS}{VW}$$

So:

$$-S \rightarrow -\tau_c$$

$$+W \rightarrow -\tau_c$$

Where τ_c is channel shear stress, γ is gravitational force, R is hydraulic radius, S is slope, Q is discharge, V is velocity, and W is width.

In addition to channel shear stress being minimal in these reaches, an increase in the width of the valley floor provides additional room for deposition of wood and debris between the valley walls and an opportunity for lateral stream migration. Floodplains, terraces, alluvial fans, and gravel bars form as a result of sediment accumulation in wide, flat reaches. These deposits are colonized by vegetation which, in turn, is prone to disturbance from high flows and transport of sediment and wood. Debris jam failure and subsequent battering of the riparian vegetation by debris during high flows removes riparian vegetation from channel surfaces, resulting in opening in the channel corridor. Bank failures and undercutting of terraces produce opening by removing vegetation while at the same time contributing sediment and debris to the channel. Lateral

channel migration across the valley floor prohibits vegetation establishment along channel margins, producing chronically opened reaches.

By contrast, reaches constrained by competent hillslopes or bedrock have limited potential for sediment accumulation. Shear stress is higher in narrow, steep reaches due to acceleration of stream flows, resulting in scour rather than deposition. In addition, floodplain development is minimal due to limited area between the valley walls for sediment storage. Without floodplain development, riparian vegetation cannot establish on the valley floor. The stream has direct interaction with the valley wall with no opportunity for lateral channel migration. Woody debris input is minor, due to lack of source areas (i.e. terraces, banks), but channels may receive wood directly from hillslopes. However, pieces tend to lodge in narrow canyons since the length of the piece is generally greater than the width of the channel; transport is rare. As a result of these factors, constrained areas have limited potential for channel widening and canopy opening.

Open canopies, though a vegetative response to channel change, are used as an indicator of sediment impacts. Open canopies result from the interplay between the same variables (slope, width) that promote sediment deposition in higher order channels. Therefore, it is conjectured that chronically opened channels are likely sites of sediment accumulation and an increase in open canopies may be produced by an increase in sediment in the system.

Channel Morphology and Pattern of Opening

The distribution of wide, flat reaches was identified using valley floor width and channel slope measured in the field in three tributaries to Elk River. A Channel Morphology Index (CMI) was created to quantitatively define channel reaches which were both wide and flat, as the combination of these two variables is more important in creating depositional zones than either variable alone.

The CMI is a product of two dimensionless indices which compare the relative width or slope at a site to channel averages. The Valley Floor Width Index (VFWI) measures the width of the valley floor relative to the width of the average active (i.e. unvegetated) channel surface (Vest, 1988). The greater the VFWI, the more unconstrained the reach is and the less potential for interaction between the active channel and the valley wall.

The slope index (SI) is a ratio of the average slope of a reach, measured 100 meters above and below a site, to the average slope of the channel. This index measures deviation from the average channel slope and can be used to compare streams with different absolute slopes. The SI was used instead of slope because it proved to be a more sensitive indicator of small, relative changes in channel gradient than the direct measurement itself. It is the small fluctuations in slope which result in flow acceleration or deceleration, promoting scour and deposition, respectively.

Since there is an inverse relationship between channel slope and valley floor width, the inverse of the Slope Index was used in

calculating the CMI. The pattern and location of wide/flat and narrow/steep reaches was obtained by multiplying the VFWI by the inverse of the SI and plotting the distribution on a graph (figures 19 a, b, c). Though there is a continuum between reach types, it appears that a CMI of about three is the cutoff between the two. Wherever the CMI is greater than three, the channel is both wide and flat, and sediment accumulation is likely. Additionally, a close spatial correlation exists between chronically opened reaches, defined as the area of channel opened throughout the study period, and the distribution of wide/flat areas. Wherever the CMI is greater than three, opening is also likely.

Change in Pattern of Opening

The dynamics of channel response were evaluated by examining the change in pattern of opening over time. If opening was strictly driven by an increase in sediment in the system then the response pattern would likely be longitudinal, with progressive opening evident downstream. This type of response has been likened to a wave of sediment moving downstream, producing progressive channel widening and aggradation as the large pulse of material moves through the system (Beschta 1983a, b, Lisle 1982, Kelsey 1980, Nolan and Janda 1979).

In the three tributaries sampled in Elk River Basin, the spatial extent of opening varied, but generally only in width (figures 20 a, b, c). The length of openings appears to be restricted by the

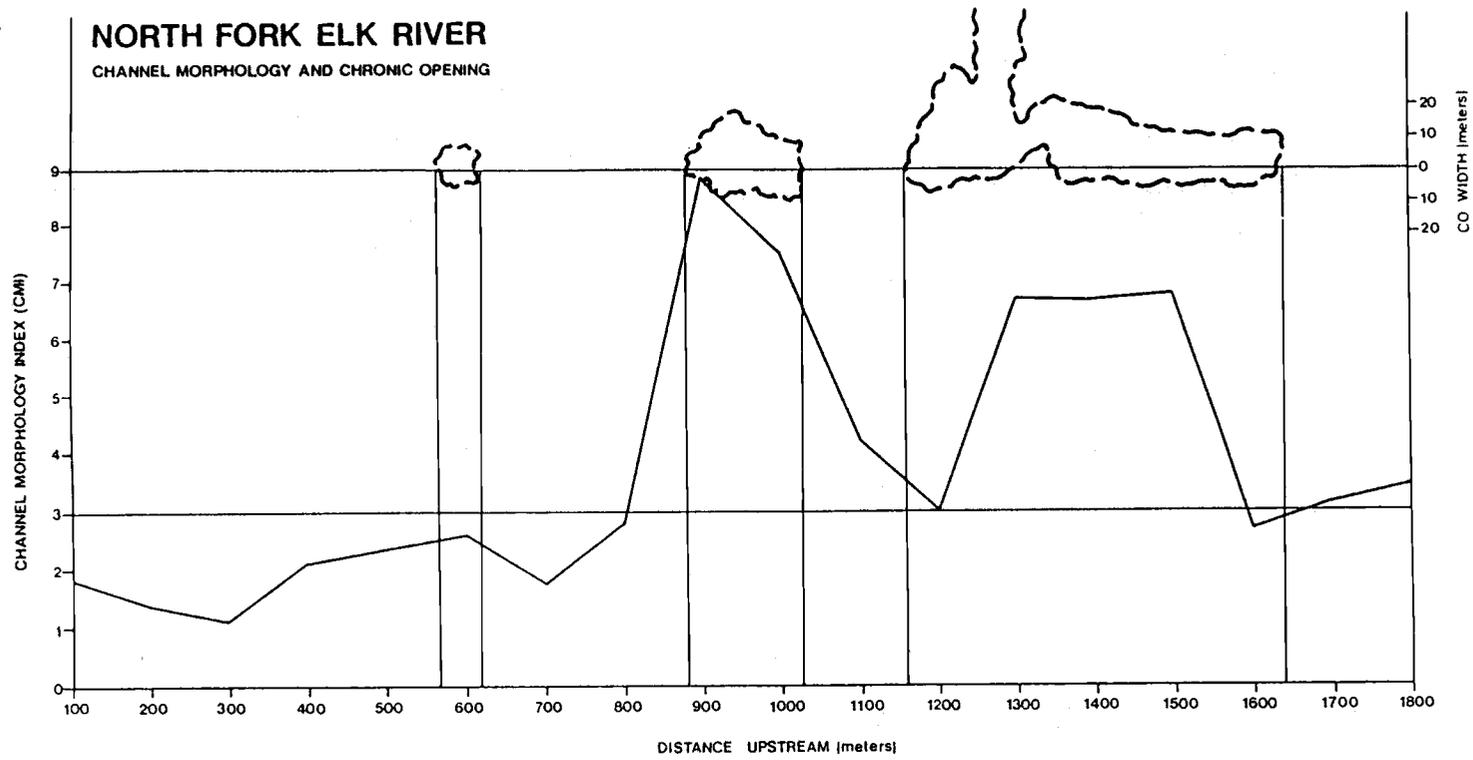
Figure 19. Distribution of constrained and unconstrained channel reaches and chronically opened reaches on three tributaries to Elk River.

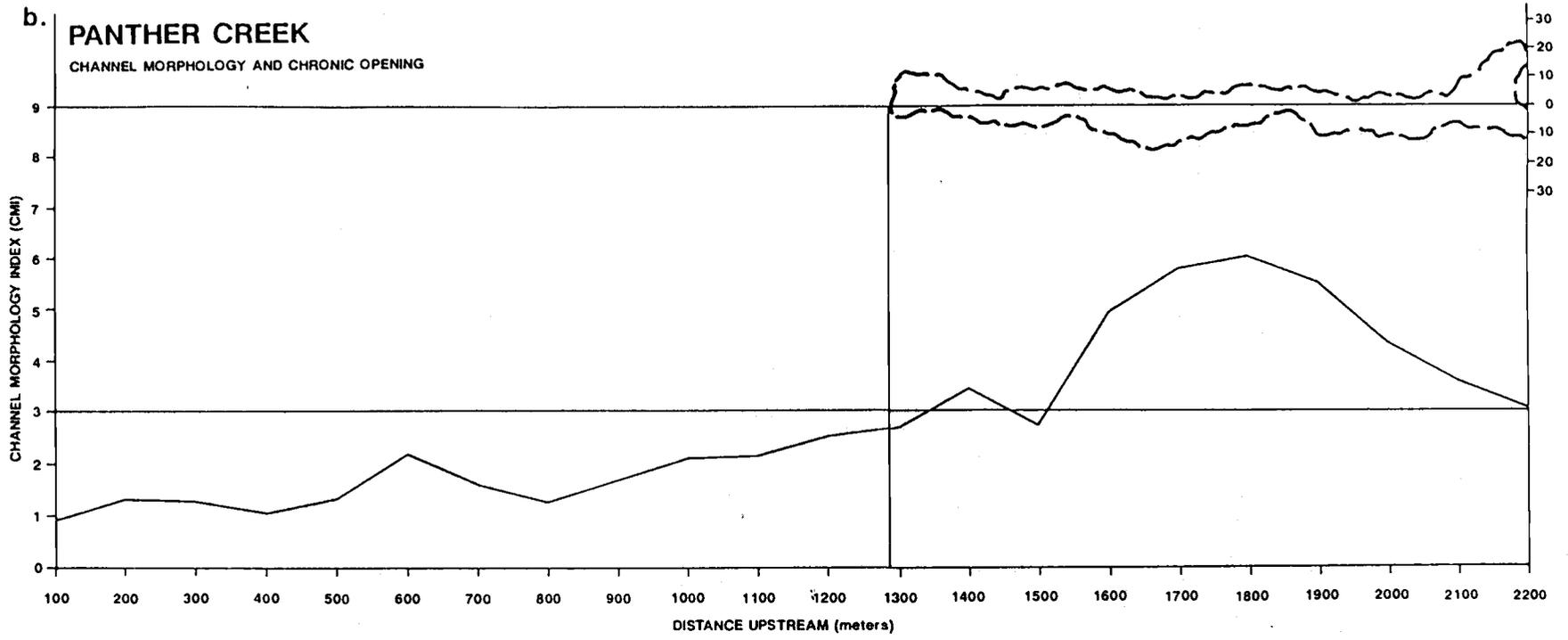
- a) North Fork Elk River
- b) Panther Creek
- c) Red Cedar Creek

— - Channel Morphology Index (CMI), a measure of relative changes in channel width and gradient. A CMI greater than three delineates reaches which are both wider and flatter while a CMI less than three delineates reaches which are both narrower and steeper.

 - Chronically open canopy reaches, defined as area of channel which maintained opening throughout the study period.

a.





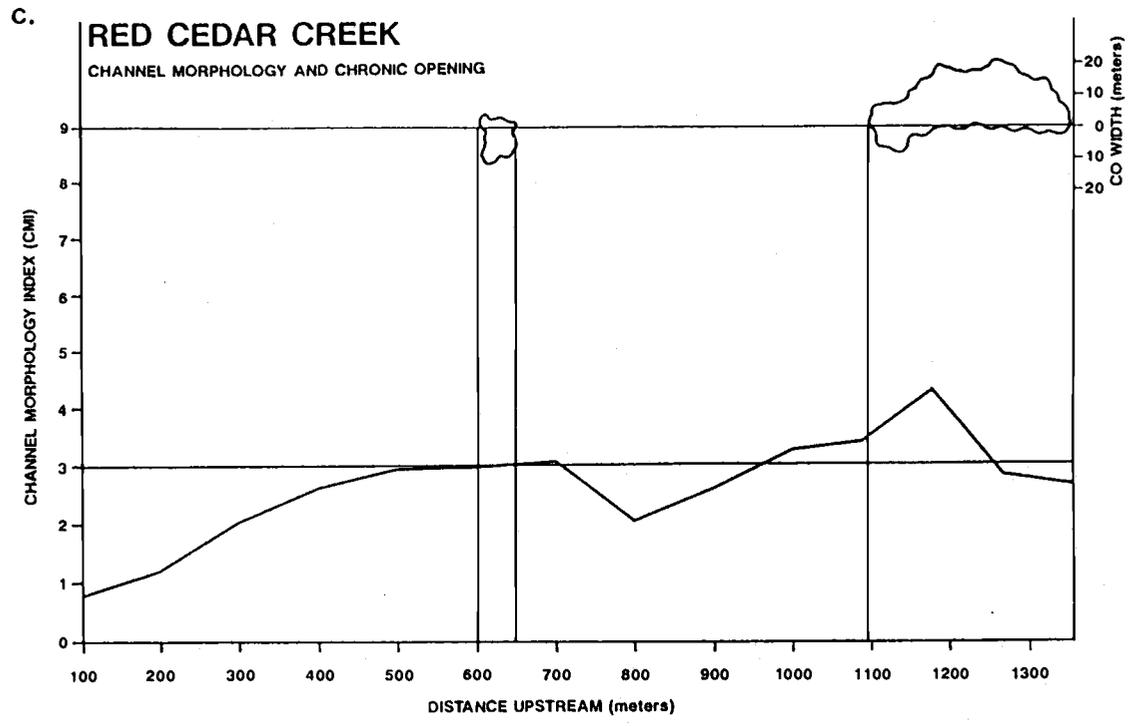


Figure 20. Change in canopy opening between photo intervals, used to monitor pattern of sediment impacts.

White areas - remained open between photo series.

White and stipple areas - opening during earlier photo series. Stipple indicates areas of revegetated surfaces.

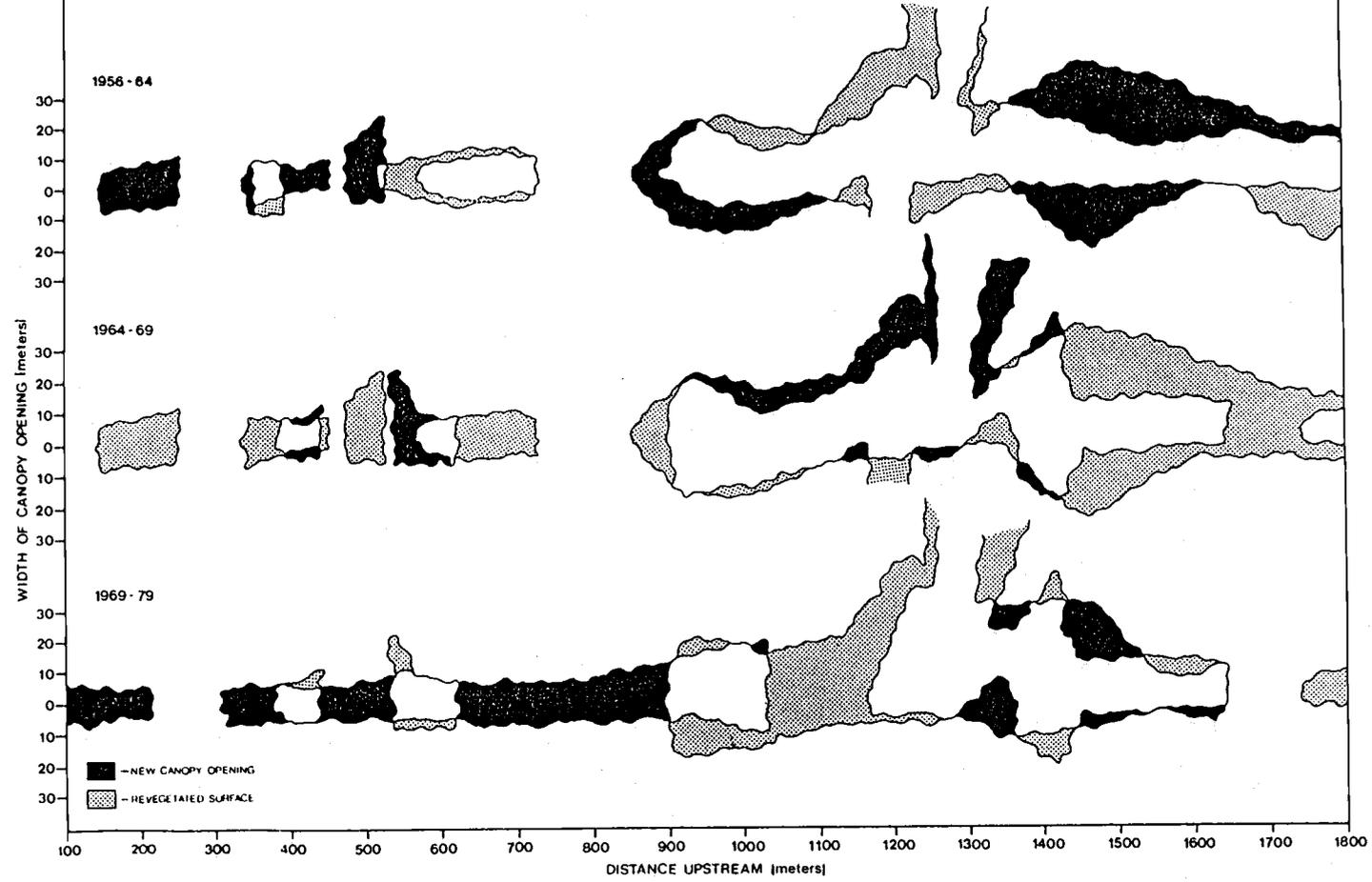
White and black areas - opening during latter photo series. Black indicates areas of new canopy opening.

- a) North Fork Elk River
- b) Panther Creek
- c) Red Cedar Creek

a.

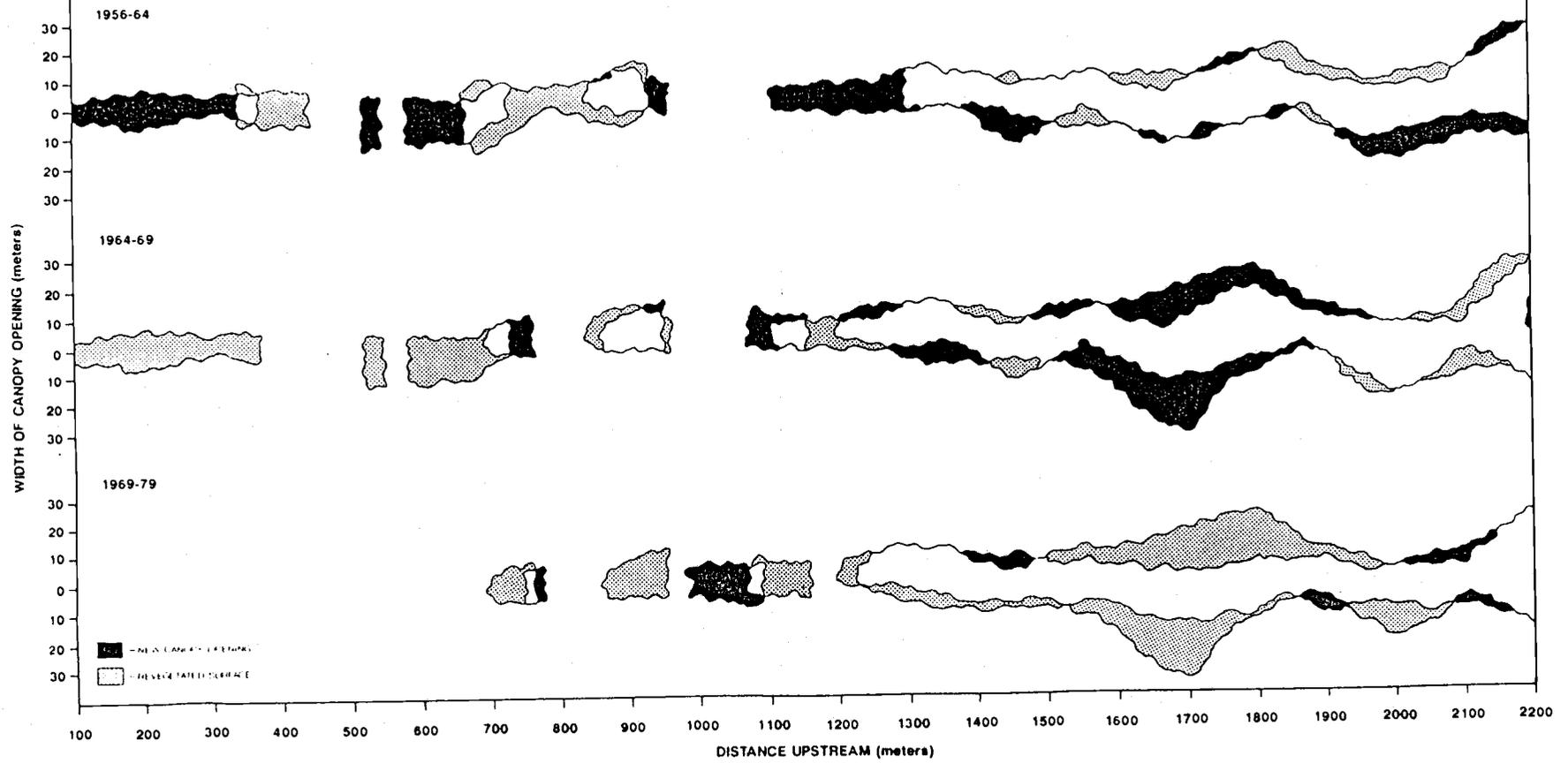
NORTH FORK ELK RIVER

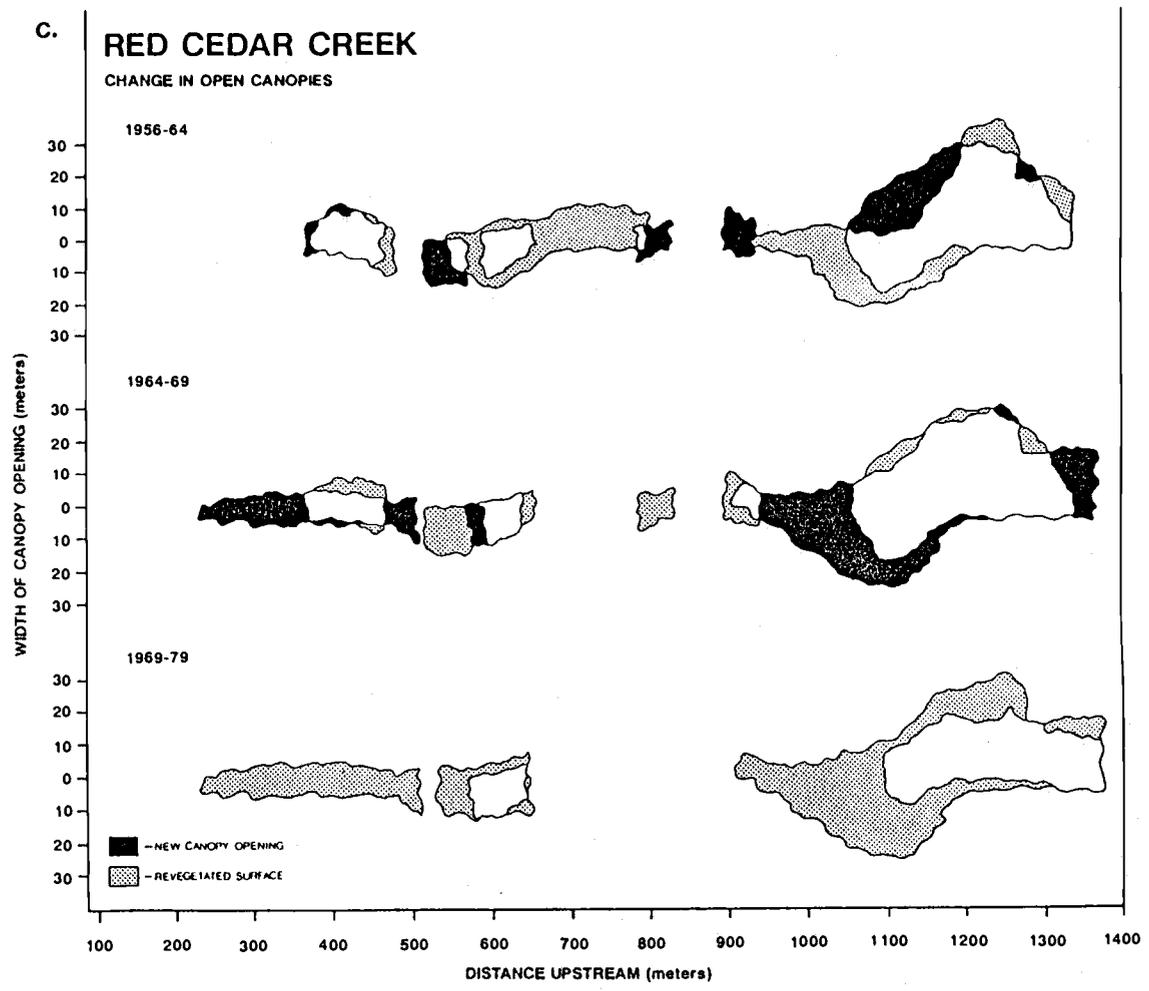
CHANGE IN OPEN CANOPIES



b.

PANTHER CREEK CHANGE IN OPEN CANOPIES





boundaries between constrained and unconstrained reaches, though some upstream and downstream expansion of opening is evident. Progressive channel opening attributable to a wave of material moving through the system was not indicated by sequential analysis of opening. This suggests that the opening was not strictly produced by an increase of sediment in the system.

Opening is more likely responding to the dynamics of water, sediment, and wood movement and the configuration of the channel and valley floor. Local influences, such as lateral channel migration, bank failure, undercutting of terraces, and debris jam failure, disturb and remove riparian vegetation from channel surfaces, producing localized openings. These openings tend to be small in constrained reaches and larger in wide, flat reaches... Where channel processes allow it, subsequent revegetation of channel surfaces results in closed canopies. Together, local sediment sources, channel morphology, and subsequent revegetation of channel surfaces produce a discontinuous and variable pattern of opening.

The reasons why sediment impacts are not more apparent in these three tributaries may be attributed to several factors including: (1) the temporal sequence of large storms and their effects on higher order channels, and (2) the limited input of material from upstream sediment sources in the three basins sampled.

Large Storms and Pattern of Opening

Channel response to large storms varied in Elk River Basin. The

two largest storms during the study period occurred in 1955 and 1964 (37 and 100 year return intervals, respectively). Though both were high magnitude, low frequency events, the distribution and pattern of opening produced by these events was very different.

The 1955 storm produced channel widening and canopy opening on several tributary channels, most notably in the wide, flat channel reaches. These areas were thinly vegetated on air photos taken in 1940. Opening was attributed to peak flows along with sediment delivery and transport. Canopies opened at this time maintained essentially the same configuration throughout the remainder of the study period, suggesting that an inherent threshold may have been crossed and open canopies are now maintained in these reaches.

The effects of the 1964 storm have been documented in basins throughout the Pacific Northwest and found to be severe and long-lasting (Grant 1986, Nolan and Merron 1985, Lyons and Beschta 1983, Lisle 1981, 82, Kelsey 1980, Nolan and Janda 1979, Stewart and LaMarche 1967, among others). Record flows, massive landsliding, and channel aggradation and widening were a direct result of this event in these studies. However, the effects of the 1964 storm in Elk River Basin were not as pervasive as in other basins. Though an increase in landsliding was documented by McHugh (1986), the change in opening in downstream channels was minimal, providing little evidence for sediment impacts attributable to this event. In fact, there appears to be a slight decline in the longitudinal extent of opening on both North Fork Elk River and Panther Creek following the 1964 event, suggesting stabilization and revegetation of channel

surfaces (figures 20 a, b).

The 1955 storm proved more effective in producing channel change than the 1964 storm, though the latter event was of higher magnitude.

Since the opening did not decline between 1956 and 1964 and extensive new opening was not produced by the 1964 storm, it is concluded that the two storms were not independent events; the condition of the channels prior to the 1964 played a large role in determining how the channels responded to the high magnitude event.

Timber Harvesting and Pattern of Opening

An additional reason why the three basins did not exhibit a response indicative of an increase in sediment in the system was because there were no big pulses of sediment delivered to these three channels from harvested hillslopes during the 1964 storm. This was due either to limited management activity in the basin or to minor amounts of material delivered to the channels from clearcut areas.

North Fork Elk River was not logged intensively during the study period - less than one percent of the basin was impacted by forest practices until the last photo interval (figure 10). Red Cedar Creek is part of a wilderness area and was not logged at all. As a result, sediment delivery from harvested slopes was minimal or nonexistent in these two basins.

On the other hand, Panther Creek was logged throughout the study period and was one of the more heavily impacted basins. Though approximately fourteen percent of the Panther Creek watershed was

harvested by 1964, open canopies linked to this activity were not apparent in the fifth order channel. In addition, the amount of material delivered to the channel from harvest related landslides was minimal. The total increase in depth of sediment would be approximately .3 meters if all of the material generated from the slides was deposited in the wide, flat reach in lower Panther Creek, based on volume estimates of landslides occurring between 1964 and 1969 (McHugh 1986). Since it is unlikely that all of this material would have reached the area at the same time, the increase in sediment delivery to the channel due to harvested related landsliding can be considered negligible in Panther Creek.

Locally, two basins did exhibit downstream channel widening and aggradation which could be directly linked to harvesting and road construction in the basin. Both Purple Mountain Creek and Butler Creek had been extensively clearcut and roaded using questionable techniques; roads had been built in or crossed the stream channel several times and whole sections of hillslopes had been harvested prior to the storm. Though both channels exhibited channel changes downstream, the processes which created these openings were different. In Purple Mountain Creek, landslides from harvested areas initiated debris torrents which travelled downstream. In Butler Creek, high rates of sediment input from dry ravel and shallow landslides produced streambed aggradation and subsequent progression of sediment and opening downstream. Though processes differed, both basins did respond to the 1964 storm, suggesting that the type and intensity of the management imprint on unstable terranes is a

significant factor in determining the amount of sediment delivered to the system and in generating downstream effects.

CHAPTER 4.

MAIN CHANNEL AND OFF-FOREST EFFECTS

Trends in Sedimentation on Main Stem Elk River

Sediment delivered to stream systems which is not readily transported through the system is stored on the valley floor in distinctive channel surfaces, including terraces, floodplains, alluvial fans, and gravel bars. Though channel morphology, processes, and history are reflected in all channel surfaces, gravel bars provide the most pertinent clues to the current flow regime and channel condition.

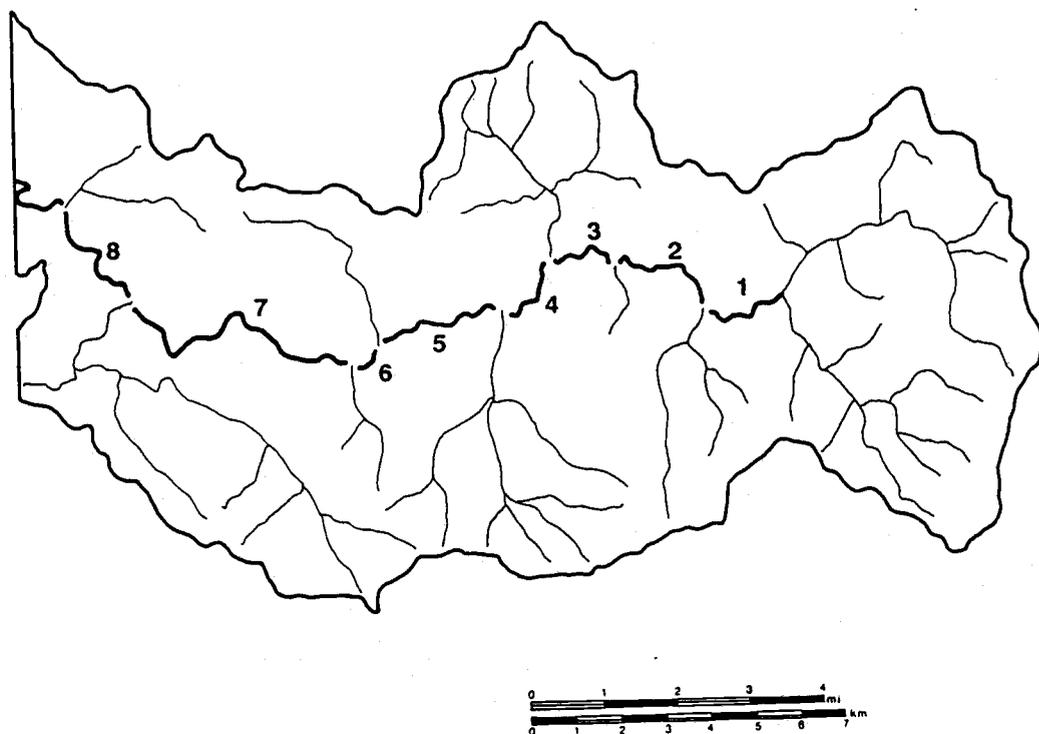
Sediment accumulates in bars at characteristic locations where flow patterns produce similar erosional and depositional sequences from one high flow event to another. Mechanisms of bar formation account for the regular spacing of bars in the channel (Richards 1976) and a quasi-stable distribution of bars over time (Church and Jones 1982). In addition, gravel bars form in association with stable channel structures, such as channel bends, bedrock outcrops, woody debris accumulations, and rooted bank projections. (Lisle 1986). For these reasons, the location and distribution of bars are fixed unless significant channel change is induced by extreme flows or sedimentation events.

With an increase in sediment in the system, both the number and size of gravel bars increase. As a coarse measure of sediment impacts on the main stem Elk River, an analysis of the change in number of gravel bars over time and space was conducted. In order to determine how the change in gravel bars was distributed over the main stem, gravel bars were tallied by channel segment (figure 21). Segment divisions occurred at junctions with major tributaries so impacts from basins with different erosional histories could be evaluated.

Generally, there was an overall increase in the total number of gravel bars in the main stem Elk River (figure 22). The greatest increase in number of bars occurred between 1956 and 1964, prior to the 1964 storm event. This increase may be due to sediment generated from the construction of Elk River road along the course of the river, in addition to sediment delivered from tributaries. The number of bars declined between 1964 and 1969, after the storm event, suggesting that, similar to findings on the tributary basins, the 1964 storm did not produce excessive sediment impacts in the basin. When major floods transport little sediment, extensive erosion rather than deposition may occur (Burkham 1972), producing a net decline in sediment in the channel and, hence, a decline in the number of gravel bars.

Distribution of Gravel Bars

In examining the locations where gravel bars increase in number, sediment impacts appear to be more substantial on the lower end of the



MAIN STEM CHANNEL SEGMENTS	LENGTH (km)
1 - JUNCTION NORTH and SOUTH FORKS to BLACKBERRY	2.18
2 - BLACKBERRY to MILBURY	3.8
3 - MILBURY to BUTLER	2.25
4 - BUTLER to PANTHER	2.06
5 - PANTHER to RED CEDAR	4.12
6 - RED CEDAR to PURPLE MTN.	0.95
7 - PURPLE MTN. to BALD MTN.	7.12
8 - BALD MTN. to ANVIL	3.34

Figure 21. Segments on main stem Elk River used in gravel bar count.

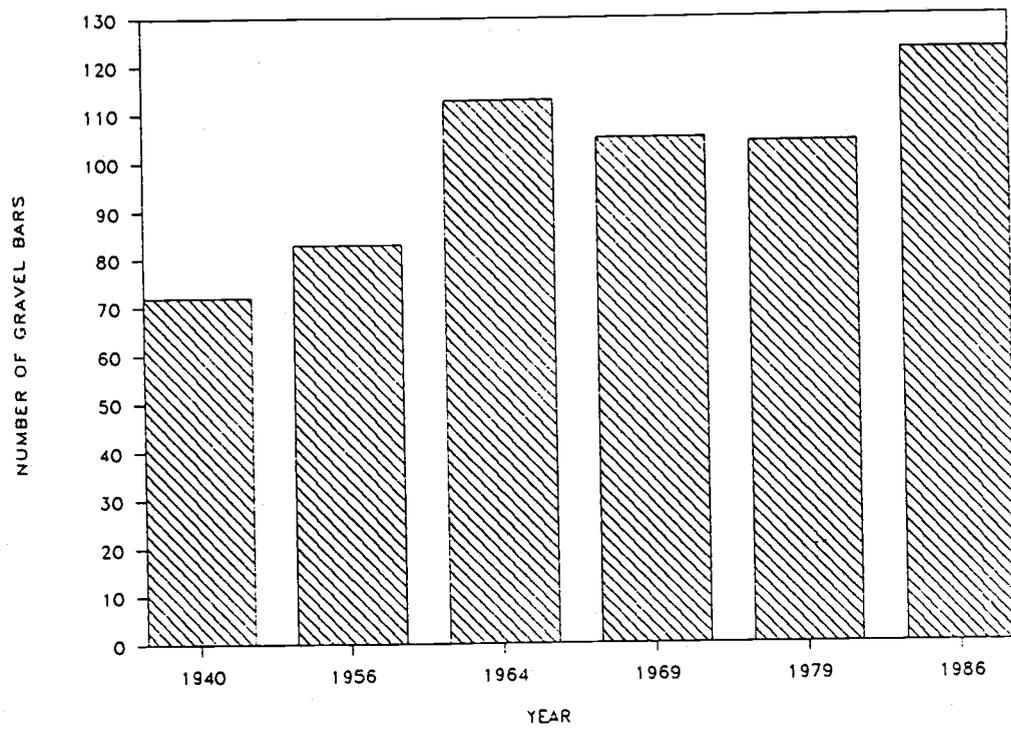


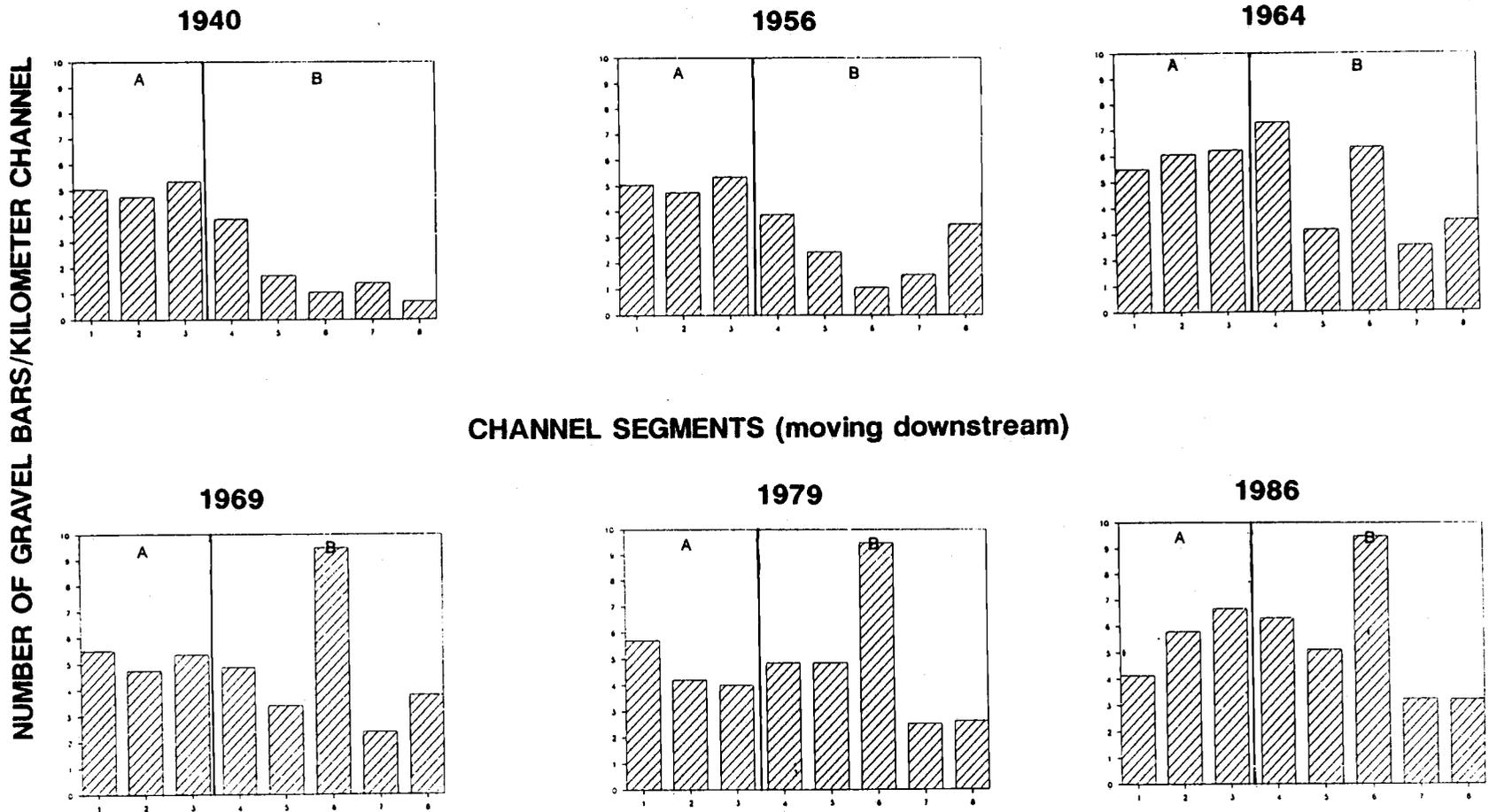
Figure 22. Total number of gravel bars in main stem Elk River by photo series, 1940-86.

main stem in segments 4-8 (figure 23). However, there was no relationship between the volume of sediment eroded in a tributary basin and an increase in the number of gravel bars downstream from the channel junction ($r^2 = .004$). This poor correlation may be due to several factors including (1) the character of sediment accumulation in the main stem Elk River and (2) the importance of large sediment events in producing observable change in accumulation.

Channels with different morphologies have varying responses to an increase in sediment, with some segments exhibiting an increase in the size of gravel bars and others exhibiting an increase the number of bars. This is largely due to whether bars were present in the channel prior to the increase in sediment. Generally, the main stem Elk River can be divided into two main segments based on gravel bar distribution in the early part of the study and change in number of bars over time.

Segment A includes the area between the junction of North and South Forks Elk River and Butler Creek while segment B includes the area from Butler Creek downstream to Anvil Creek.

Segment A is wider, flatter, and has a more alluvial character. Gravel bars were concentrated in this area on air photos taken in 1940 and 1956. The response to an increase in sediment was an increase in the extent of individual bars rather than an increase in the number of bars. Conversely, segment B flows through a bedrock canyon. Bar formation is limited due to an acceleration of flows and an increase in shear stress on the bed of the channel, limiting sediment deposition. With an increase in sediment load, however, channel



CHANNEL SEGMENTS (moving downstream)

Figure 23. Number of gravel bars by segment and by photo series, 1940-86. Letters indicate channel segments of essentially different morphologies.

capacity can be locally overwhelmed and transport capabilities reduced. At these points, sediment deposition occurs and gravel bars form, usually in association with stable channel features. These bars tend to be smaller and more isolated than those in upstream reaches, but may continue to grow with additional sediment inputs.

Given this observation on the patterns of sediment accumulation based on channel morphology, the change in number of gravel bars is not an adequate indicator of sediment impacts in all parts of the channel. An increase in the number of bars has more suitable application in steep/narrow reaches than in wide/flat reaches. This skews the gravel bar count in favor of constrained reaches, making the sediment impacts in the wide, flat reaches less conspicuous. The skewed count could account for the poor correlation between the volume of material eroded in a basin and the change in number of gravel bars downstream.

Additionally, since debris flows are not common in the basin, material delivered from the hillslopes will take considerably longer to move through the system via fluvial processes. The timing of impacts in the main stem may be delayed due to the relatively slow transport rate of fluvial processes compared to transport by debris flows. Also, sediment delivery may need to be extreme, rapid, and overwhelm the capacity of the channel before impacts are observed downstream. Tributaries in Elk River Basin did not exhibit this type of channel response, with the exception of Purple Mountain Creek.

Severe channel aggradation was apparent in the main stem below the junction with Purple Mountain Creek. Both channel widening and an

increase in the number and size of gravel bars were observed on the photographs taken after the basin was harvested. As discussed earlier, landslides from harvested areas initiated debris flows in Purple Mountain Creek and travelled into the downstream portion of the basin (Chapter 3). Material from this tributary entered the main stem and produced net aggradation downstream, more so than on other segments of the main stem. McHugh (1986) also noted these changes in this main stem segment and attributed them to a net increase in sediment from the tributary accompanied by a large bend in the channel downstream which promoted deposition.

Off-Forest Effects

Changes in sediment accumulation in the main stem of Elk River below its junction with Anvil Creek were examined qualitatively to determine whether an increase in sedimentation was apparent downstream of the forest boundary. This portion of the channel is more prone to sediment impacts than the upstream segments due to the character of the channel and the history of land use. The valley floor below the Anvil Creek junction changes abruptly from a bedrock canyon to a wider, flatter, more alluviated valley. Sediment deposition occurs due to a reduction of bed shear stress and sediment transport capacity associated with the change in channel morphology. Additionally, the land cover has been altered by man's activity, changing from forest to agricultural vegetation. Removal of the forest, specifically from riparian areas, has a destabilizing effect on a channel; riparian

vegetation not only serves as an energy dissipator during high flows but the vegetation roots help stabilize channel surfaces. Moreover, the boundary of the Siskiyou National Forest ends and private ownership begins at this junction. There are fewer land management constraints on privately owned lands, subjecting them to, perhaps, questionable management techniques and leading to an increase in local sediment inputs.

A comparison of air photos taken in 1940 and 1986 indicates that visible changes in channel morphology consistent with an increase in sediment have occurred during the forty-six year period. Channel changes include: (1) an increase in the number of gravel bars, (2) an increase in the size of existing gravel bars, (3) loss of riparian forest, (4) an apparent decrease in depth, as determined by tonal and color variation on the photos, and (5) channel widening and an increase in the width of active channel surface.

All of this evidence suggests that the channel has become shallower and wider since 1940. How much of this can be attributed to logging in the upland areas cannot be determined from the information presented here; that would require a complete sediment budget analysis (Swanson et. al., 1982) and is beyond the scope of this study. Factors other than upstream logging which may have influenced the amount of sediment deposited in this portion of the channel include local agricultural and residential activity, local channel "maintenance" projects, logging on private lands on hillslopes above this channel segment, and cutting of the riparian forest.

Though the local sources of sediment have contributed to change

in channel morphology below Anvil Creek, sediment impacts from upbasin logging cannot be disregarded. By looking at the rates of sediment transport in studies done on other basins, one can obtain an idea of how long it might take for material to move through a drainage network and affect the lower portions of the basin. In the Puget Lowland of Washington, Madej (1982, p. 107) found that "sediment placed in the channel by present disturbances will take on the order of twenty to forty years to be removed". Lisle (1981, 1982) found that it took five to twenty years for channel bed morphology to recover from disturbance, as the excess material was removed from the area. Wolman and Gerson (1978) suggest that stream channels in mountains in temperate climates recover quickly after a major disturbance, usually on the order of a decade. This information indicates that the rates of sediment movement in other basins is on the same order of time that it would have taken for sediment generated in Elk River tributaries to reach the lower end of the main stem. Therefore, it cannot be discounted that some (though not all) of the sedimentation effects in the lower parts of the basin may have come from upbasin disturbances.

However, the results from the aforementioned studies are highly site specific. Differences in input rates, particle size distribution, and channel geometry affect the rates and timing of sediment movement in a basin. Sediment transport rates from other regions are not directly applicable in Elk River Basin and are used for comparison only.

DISCUSSION AND CONCLUSIONS

Downstream effects refers to the off-site changes in hydrology, sediment transport and storage, and woody debris accumulation in stream channels in response to harvesting activities. These effects are both spatially and temporally removed from the original site of disturbance and include channel widening and aggradation, channel instability and lateral shifting of the stream, bank erosion, and removal of riparian vegetation. In order to effectively evaluate downstream effects, the linkages between the upslope sources of material and the pattern of downstream sediment impacts need to be identified and assessed.

In this study, sediment impacts were interpreted from aerial photography, using an increase in the opening of the riparian canopy cover as an indication of channel disturbance. Though a vegetative response to disturbance, opening is produced by large scale changes in water, sediment, and debris delivery and movement in a basin and can be used to monitor sediment and hydrologic impacts. Sequential air photos were used to determine the timing, magnitude, location, and persistence of opening relative to management activity and large storms.

Summary of Results

Results from this study show that while open canopies

occurred in both logged and unlogged basins, the likelihood of a channel exhibiting opening increased as the basin was harvested. New opening occurred mainly in low order tributary basins and was directly attributed to timber harvesting and road construction. Landslides from clearcuts and roads were the most common source of sediment delivered to stream channels. However, landslides in low order basins did not generate extensive debris flows, with exceptions noted locally. Without debris flows, openings initiated by landslides did not extend very far away from the initial site of disturbance, hence, downstream channel changes could not be directly linked to upslope forestry activities.

Openings in higher order channels occurred throughout the study period, mainly in wide, flat channel reaches. The distribution of these reaches was controlled by geologic structure, including faults, folding, and differences in competence between rock types. These wide, flat reaches are prone to sediment impacts due to the deceleration of flows and decline in channel shear stress associated with an increase in width and decrease in gradient. In addition, lateral channel migration across the wide valley floor and the reworking of bed and bank material helps keep these reaches open.

Initial opening in higher order channels was attributed to a high magnitude event in 1955 which caused local bankside failures and battering of vegetation on channel surfaces; prior to this event, channel surfaces were vegetated. Canopies opened at this time maintained essentially the same configuration throughout the

study period even with increased sediment introduced from harvested areas and the occurrence of several large storms. Progressive channel opening attributed to a pulse of sediment moving through the channel was not evident in these basins.

The 1964 storm was the highest magnitude event in the study period, yet did not produce catastrophic channel changes on the same order of magnitude as other channels in the Pacific Northwest and Klamath Mountain Province. Exceptions were noted in two basins which had been harvested using techniques which produced severe environmental disturbance. Downstream canopy opening, channel widening, and aggradation were produced by debris flows and surface erosion from harvested areas in these basins.

The change in number of gravel bars on the main stem of Elk River indicated that there was a net increase in sediment in the channel. How much of this could be attributed to the natural variability of the system or to downstream effects from tributary basins could not be determined from this analysis. Locally, inputs from Purple Mountain Creek basin did produce channel widening and an increase in size and number of gravel bars in the main stem Elk River. This was the only tributary which contributed sediment to the main stem where impacts could be directly linked to upslope management activity. Effects were attributed to debris flows from harvested areas which travelled downstream and reached the main stem of Elk River, dumping sediment and debris into the channel. Sediment impacts from

timber harvesting downstream of the forest boundary could not be completely discounted, though it was more likely that channel changes produced below the forest boundary were from local land uses rather than upstream forest practices.

Factors Contributing to Channel Response in Elk River Basin

The original purpose of this investigation was to determine whether downstream effects could be detected in fourth to fifth order channels and linked to forestry activities upslope. Evidence indicates that downstream effects are active in the Elk River Basin, but only on a local scale. This type of channel response is attributed to four factors: lack of significant debris flows in most parts of the basin, channel constraint and limited potential for opening of riparian canopy in bedrock-hardened reaches, the influence of a sequence of storm events on channel conditions, and essentially pristine conditions at the time of the high magnitude event.

Though landsliding and canopy opening occurred in all terranes in Elk River Basin, extensive debris flows and continuously open reaches were not common. Debris flows are rapid and catastrophic mechanisms of sediment transport which disrupt channel morphology and batter riparian vegetation. Without debris flows, the primary mechanism of sediment transport is via fluvial processes. Peak flows without mass movement do not appear to be as effective in producing downstream channel

changes. Competent, rapid, and voluminous sediment delivery to the system may be required before downstream effects become evident.

Still, the increase in landsliding did dump a considerable amount of sediment and debris into stream channels (McHugh 1986). Given that many channels in Elk River Basin are steep and bedrock constrained, it is possible that debris flows could move downstream without disturbing the riparian canopy. This would explain a lack of spatial linkage between upslope disturbances and downstream sediment impacts and still account for an increase in opening downstream. However, higher order channels in the basin generally did not exhibit sediment impacts which were coincident with timing or intensity of timber removal upstream. The pattern of opening was out of sync with upslope activities, indicating that opening was produced by local sediment sources and channel processes rather than an overriding sediment imprint.

Channel response to large storm events varied during the study period, with moderate storms producing significant effects and a high magnitude event producing only minor sediment impacts.

Evidence presented indicated that the sequence of storms in time is as important as the magnitude of the event in influencing channel capacity and the morphology of the channel at any one instant (Beven 1981). Channels may have been altered to such an extent by the earlier event that the 1964 storm did not produce additional impacts which were evident on the photographs (i.e. no additional opening). This not only suggests that the 1964 storm

was not a big depositional event, but that only a large depositional event produces downstream effects.

Perhaps the most important factor influencing channel response during the 1964 event was that much of Elk River Basin was in pristine condition at the time and sediment delivery from harvest-related landslides was limited to a few basins. Had other parts of Elk River Basin been harvested at the time of the storm, additional channels would have likely exhibited downstream effects. Other evidence of the potential for downstream effects can be found in Euchre Creek and Sixes River, two basins with similar lithologies bordering the study site; both had more area impacted by timber harvesting and roads than Elk River Basin and both exhibited channel widening and aggradation in response to the 1964 storm (Frissell, personal communication).

Management Implications

Results from this study have several implications for land managers required to assess the potential impacts of planned activities on stream channels and fish habitat downstream. Present means of addressing cumulative watershed effects employ arbitrarily established requirements for harvest limitation and dispersion as a means of mitigating effects. These are essentially accounting procedures in forest planning models and do not take the physical character of the site into consideration. Since channel responses are largely influenced by

the inherent basin sensitivity to forestry practices, the assumptions behind the current methods of assessing these impacts are suspect. Present mitigation measures may underestimate the long-term and cumulative impacts of sediment and are not adequate for the task at hand.

Unfortunately, there is no simple model which determines how much harvesting can occur in a basin before detrimental impacts occur - at least none that is predictive with suitable accuracy. A better way of mitigating these effects is to use an analysis similar to the one in this study to identify both erosional potential and sensitive riparian areas and limit harvesting in areas with a high potential for sediment impacts. Also, results from this study indicate that the location of harvest areas with respect to the channel and type of harvesting techniques used play a considerable role in determining the extent of effects downstream. Employing management techniques such as zoning of sensitive areas, use of headwall leave areas and buffer strips, and proper road construction and design may reduce the potential for detrimental sediment impacts in a basin.

In addition to identifying sensitive hillslope and riparian area, a baseline monitoring system should be established in basins with planned timber sales in order to detect incremental changes after harvesting. This would include both field investigation and air photo interpretation similar to the ones used in this study. Periodic evaluation of channel conditions would determine if the methods of mitigating these impacts are

effective and what changes need to be made in order to improve upon them.

In summary, air photo interpretation did prove useful for determining the erosional processes active in the basins, the changing condition of the channel over time, and the areas of the channel with a high potential for detrimental sediment impacts. The use of the RAPID technique was considered experimental in the Elk River Basin. The technique was developed in the Western Cascades of Oregon and the assumptions used were based on processes in this region. The assumptions do appear to be valid in Elk River Basin since the downstream channel response was indicative of the hillslope processes active in the basin.

However, one needs to recognize that the interaction between the geology, climate, topography, vegetation, and management imprint will ultimately determine how effects are generated and exhibited in stream channels downstream. Caution should be applied when using the technique in areas where the environmental conditions are considerably different. Still, historical analysis of the relationships between management activity, hillslope processes, and channel conditions can be interpreted from air photos cross-regionally, even though the sources and processes of downstream effects may vary between sites.

Leopold (1980) stated in an address on the cumulative effects of forest management, "To suppose that upstream changes in hydrologic parameters have no effect downstream flies in the face of principles of general physics on which modern science is

built." Based on these principles, it is apparent that activities in the upper portion of the basin will ultimately effect the channels downstream. However, the magnitude of these channel changes is variable. Channel change in Elk River Basin was not on the same order as other parts of the Pacific Northwest due to the specific suite of erosional processes, the morphology of the channels, and the distribution and timing of management activity in the basin relative to large storms.

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