



A spatial comparison of channel morphology between burn, timber and old growth areas within the Yellowstone ecosystem
by Stephen Charles Myers

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University
© Copyright by Stephen Charles Myers (1997)

Abstract:

This study evaluates whether mountain stream channel morphology responds to differences in land cover and land use and whether a spatial approach can be used to document these differences. Specifically, this study examines if first order stream morphology varies between watersheds with extensive clear-cuts, fire disturbance, and old growth in Yellowstone National Park and Targhee National Forest. The study area is in the southwestern part of the Yellowstone rhyolite plateau, a region of relatively uniform geology, topography, slope, elevation and climate. Twenty first order streams within each land use were randomly selected. Measurements include bank full width, depth, sinuosity, bed material size, watershed area, elevation, valley slope, bank vegetation, and the amount of woody debris in the stream channel. Independent variables could be adequately controlled only for old growth and clear-cut streams. The burned area had higher channel slope; for this reason trends could only be determined between the old growth and clear-cut areas. Relative to old growth, streams in the clear-cut area appear to be less sinuous, wider, shallower, and have less bank vegetation. These findings suggest that stream morphology responds in different ways to clear-cutting. A spatial approach, where characteristics of multiple watersheds and channels are compared, provides a useful alternative to monitoring only one or two channels over many years. A limitation of such an approach is the required control over independent variables making it difficult to apply to all landscapes. The multiple watershed comparison captures a greater range of channel responses and enables the development of regional models for prediction of a channel response to land uses if the land use areas have similar independent variables.

A Spatial Comparison of Channel Morphology
Between Burn, Timber and Old Growth Areas
Within the Yellowstone Ecosystem

by

Stephen Charles Myers

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana

May 1997

N378
M9924

APPROVAL

of a thesis submitted by

Stephen Charles Myers

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

May 1, 1997
Date

W. Andrew Marcus
Chairperson, Graduate Committee

Approval for the Department of Earth Sciences

May 1, 1997
Date

W. Andrew Marcus
Head, Major Department

Approval for the College of Graduate Studies

5/2/97
Date

R. Brown
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature: Stephen T. Meyer

Date: 1 MAY 1997

ACKNOWLEDGEMENTS

I offer my sincere thanks to my advisor, Dr. W. Andrew Marcus. His passion for fluvial geomorphology and desire to teach has been an inspiration to me throughout my research. Without his encouragement, professional advice and wisdom this research could never have been realized. I am also indebted to my other committee members, including Dr. Stephan Custer, who always provided a great deal of common sense and the required geologic view point; and Dr. Paul Hook, for his interdisciplinary advice in the range sciences and his unique perspective.

Funding for this project was provided by the United States Army, the Cinnabar Foundation, the Henry's Fork Foundation, the Barry C. Bishop Scholarship for Mountain Research, the Yellowstone National Park and the Targhee National Forest. I appreciate their investment in my research.

I also offer my thanks to my field assistants, Craig Sauer and Drake Burford, Mark Stroud for cartographic work and to Vicki Steele for assistance with statistical analysis. Finally, to all of my family and friends for their encouragement and support.

TABLE OF CONTENTS

	Page
1. INTRODUCTION.....	1
2. PREVIOUS RESEARCH.....	2
Timber Impacts.....	2
Fire Impacts.....	5
3. STUDY AREA AND METHODS.....	8
Study Area.....	8
Methods.....	13
4. DATA PRESENTATION.....	16
Watershed Variables.....	16
Intermediate Morphologic Variables.....	18
Channel Response Variables.....	18
5. DATA ANALYSIS.....	22
Kruskal-Wallis Comparison.....	22
Scatter-Plot Analysis.....	25
Old Growth Streams vs. Clear-cut Streams.....	26
Old Growth Streams vs. Fire Streams.....	31
Multivariate Analysis.....	32
6. CONCLUSION.....	36
LITERATURE CITED.....	39
APPENDICES.....	46
Appendix A-Old Growth Data.....	47
Appendix B-Clear-cut Data.....	52
Appendix C-Fire Data.....	57
Appendix D-Clear-cut, Year Cut Data.....	62

LIST OF TABLES

Table	Page
1. Study Site General Characteristics.....	11
2. Kruskal-Wallis Comparison	23
3. Dunnett T Test Results	24
4. Summary of Regression Analysis-Watershed Variables	33
5. Summary of regression Analysis-Intermediate Control Variables	34

LIST OF FIGURES

Figure	Page
1. Map of the study area in the Greater Yellowstone Ecosystem	9
2. Map of study sight locations within the study area	10
3. Box-plots of land use by watershed area and channel slope	17
4. Box-plots of land use by intermediate morphologic response variables	19
5. Box-plots of land use by channel response variables	20
6. Scatter plots of channel slope by intermediate morphologic response variables	27
7. Scatter plots of channel slope by channel response variables	28
8. Scatter plots of sinuosity, bankfull width and depth by bare ground	30

ABSTRACT

This study evaluates whether mountain stream channel morphology responds to differences in land cover and land use and whether a spatial approach can be used to document these differences. Specifically, this study examines if first order stream morphology varies between watersheds with extensive clear-cuts, fire disturbance, and old growth in Yellowstone National Park and Targhee National Forest. The study area is in the southwestern part of the Yellowstone rhyolite plateau, a region of relatively uniform geology, topography, slope, elevation and climate. Twenty first order streams within each land use were randomly selected. Measurements include bank full width, depth, sinuosity, bed material size, watershed area, elevation, valley slope, bank vegetation, and the amount of woody debris in the stream channel. Independent variables could be adequately controlled only for old growth and clear-cut streams. The burned area had higher channel slope; for this reason trends could only be determined between the old growth and clear-cut areas. Relative to old growth, streams in the clear-cut area appear to be less sinuous, wider, shallower, and have less bank vegetation. These findings suggest that stream morphology responds in different ways to clear-cutting. A spatial approach, where characteristics of multiple watersheds and channels are compared, provides a useful alternative to monitoring only one or two channels over many years. A limitation of such an approach is the required control over independent variables making it difficult to apply to all landscapes. The multiple watershed comparison captures a greater range of channel responses and enables the development of regional models for prediction of a channel response to land uses if the land use areas have similar independent variables.

CHAPTER 1

INTRODUCTION

Channel morphology reflects both local conditions and channel position in the watershed (Harr, 1987). Numerous studies have examined stream channel responses to land use with paired watershed or temporal approaches (Troendle and King, 1985). A paired approach uses a control reach and compares it to a reach that has been effected by a different land use, while the temporal approach investigates the effects of a land use on channel morphology through time (Satterlund and Adams, 1992). Paired watershed studies are restrictive in that the data is only applicable to streams similar to the investigated stream. Temporal approaches require longer periods of time to effectively document stream channel change and only provide information about the response of one or two streams. A spatial approach that examines a large number of streams within an area of homogenous climate, topography and, geology might provide more insight into the range of responses of stream channel morphology to different types of land use.

This study explores whether mountain stream channel morphology responds to differences in land use and evaluates whether a spatial approach can be used to document these differences. Specifically, I examine if first order stream morphology in 60 streams varies between watersheds with extensive clear-cuts, fire disturbance, and old growth in the Greater Yellowstone ecosystem. I also discuss the potential for using a multiple watershed comparison approach to develop regional models for describing and predicting the full range of potential channel responses to a specific land use.

CHAPTER 2

PREVIOUS RESEARCH

Land use practices such as clear-cut logging and fire affect stream morphology through four primary mechanisms (Leopold, 1980; Harr, 1976). The runoff regime within the watershed is altered due to changes in evapotranspiration, reduced interception, and altered snow accumulation patterns (Cline et al., 1977; Meghan, 1983; Troendle and Leaf, 1985). The sediment load and sediment sizes carried by impacted streams vary due to changes in the availability of transportable sediment and changes in runoff regime (Leopold et al., 1964). Logging activities can directly alter the physical characteristics of the stream bottom and banks through mechanical action, such as development of skid trails, building of slash piles, and removal of bank vegetation. A final process that influences stream morphology is the introduction or removal of large woody debris into or from the stream channel (Beschta and Platts, 1986; Bilby and Ward, 1991). Most work on the effects of land use on stream channels has focused on these processes, but more research is needed to directly examine morphologic changes of the stream channel.

Timber Impacts

Timber harvest activities affect the magnitude and frequency of the discharge within a drainage basin by reducing interception loss, reducing transpiration, increasing snow accumulation, and increasing melt rates (Bosch and Hewlett, 1982; Cheng, 1989; Cline et al., 1977; Johnston, 1984; Keppler and Zeimer, 1990; King, 1989; Meghan, 1983; Rothacher, 1970; Troendle and Leaf, 1985). Increases in annual runoff from clear-

cutting range from negligible (Cheng, 1989; Johnston, 1984) to quantities ranging from 100 millimeters to 500 millimeters (Cline et al., 1977; Rothacher, 1970). In Northern Idaho, increases in annual water yield as a result of clear-cut operations range from 112 millimeters to 889 millimeters (Cline et al., 1977). Cline and others concluded these increases in annual water yield could be expected with vegetation removal, due in part to decreased evapotranspiration. They also found that other considerations such as slope orientation wind exposure, forest stand density and stand structure affect the annual water yield increases. In the mountains of western Oregon, increases in annual water yield ranged from 208.3 to 457.2 millimeters (Rothacher, 1970). In British Columbia, Cheng (1989) provided evidence that increases in annual water yield ranged from 10 millimeters to 59 millimeters could be expected from harvested drainage basins. Annual peak flows increased by 21% (Cheng, 1989). In contrast, Johnston's (1984) research in the Wasatch Mountains near Salt Lake City, Utah showed no significant increases in annual water yield or annual peak flows in the four years following clear-cut logging. This was attributed to the relatively small size of the clear-cut and minimal disturbance during the harvest. The timing and magnitude of increases in streamflow, peak flow and snow accumulations appear to be regionally specific and to depend on the hydrologic regime of the study area.

The changes in hydrologic regime in response to timber harvesting can cause increases in peak and total annual sediment loads (Anderson and Potts, 1987; Brown and Krygier, 1971; Duncan et al., 1987; Rice et al., 1979; Troendle, 1983; Troendle and Leaf, 1985). In the Pacific Northwest, documented peak sediment load increases range from a doubling following road construction and a tripling following clear-cut activities (Brown and Krygier, 1971) to a seven fold increase in the mountains of western Montana

(Anderson and Potts, 1987). The reasons for increases in sediment load include flashier responses of the stream, increases in spring runoff, and increases in available sediment as a result of logging activities in the watershed (Rice et al., 1979). The changes in sediment load vary regionally and no one coefficient can be applied to all settings where clear-cut activities have taken place.

In contrast to the extensive research on timber harvest effects on sediment load and water yield, there is relatively little work assessing impacts of timber harvest on stream channel morphology in mountain environments (Grant, 1988; Heede, 1991; Marston and Wick, 1994; Overton et al., 1993; Wick, 1995). Marston and Wick (1994) studied the downstream effects of timber harvests on the morphology of small mountain streams in the Medicine Bow Mountains of Wyoming. They were not able to document differences in stream channel morphology as a result of clear-cutting, perhaps because of natural variations which obscured the response. Heede (1991) demonstrated that first order ephemeral streams in Arizona become wider and show an increase in knick point frequency after timber harvest. Overton et al., (1993) observed that clear-cut activity in Idaho caused differences in substrate size and caused an overall decrease in the quantity of large woody debris effecting stream channel flow. Grant et al. (1983) developed an air photo technique, called the RAPID Technique, to document stream channel morphology. Using this technique in the Middle fork of the Willamette River in the Cascade Range of Oregon, Grant (1988) demonstrated that timber harvest activities cause increased streamside openings, which are areas of no tree cover. Lyons and Beschta (1983) used air photos to document stream channel change through time in Oregon and found that channel width increased, large woody debris decreased, and sinuosity remained constant after timber operations in the watershed.

Fire Impacts

There is less research on the effects of fire on stream channels than there is on the effects of timber harvest on stream channel morphology. Reviews of fire effects on streams by Tiedemann and others (1979) and Swanson (1981) both identified the need for more research on the effect of fire on geomorphic process. Research on the influence of fire has generally documented increases in overland flow, increases in water yield, and increases in sediment availability (Brown, 1972; Farnes and Hartman, 1989; Robichaud and Waldrop, 1994; Swanson, 1981; White and Wells, 1979; Wright and Bailey, 1982). Increases in overland flow can be expected following spring runoff. These increases range from eight times greater in western Montana (Wright and Bailey, 1982) up to sixty times greater in the mountains of New Mexico (White and Wells, 1979). Brown (1972) documented similar increases in water yield and overland flow in Australia. The increases in overland flow and water yield are directly related to the reduced interception of the burned forest canopy, reduced vegetation transpiration, and hydrophobic soil conditions (Robichaud and Waldrop, 1994; Wright and Bailey, 1982).

Increases in annual sediment yield also occur as a result of fire activity (Swanson, 1981; Tiedemann, 1979; Troendle and Bevenger, 1996). The increases range from 5 fold in the Shoshone National Forest of Wyoming (Troendle and Bevenger, 1996) to 30 fold in the streams of California (Swanson, 1981). These increases in sediment yield were attributed to decreased riparian vegetation, which destabilized banks, the formation of hydrophobic soils, and increased runoff on slopes with decreased vegetation (Troendle and Bevenger, 1996; Swanson, 1981). The increases in sediment yield vary according to the climate and runoff regime within a specific region.

Although there is extensive literature on the role of woody debris in streams (Beschta and Platts, 1986; Bilby and Ward, 1991; Sedell et al., 1988) there is little research on the effects of fire on the amounts or role of woody debris on stream morphology (Minshall and Robinson, 1992; Young and Bozek, 1996). Young and Bozek (1996) concluded that large woody debris in stream channels in burn areas of the Greater Yellowstone Ecosystem moved four times as far as woody debris in comparable unburned watersheds. Minshall and Robinson's (1992) work also showed an initial increase in the volume and frequency of large woody debris in stream channels following a fire event, followed by a decrease in large woody debris five years after the disturbance. Both studies attribute the changes in woody debris to increased availability of dead wood and increased runoff to carry the wood to the streams.

Relatively few studies have documented the impacts of fire on stream morphology (Minshall and Robinson, 1992; White and Wells, 1979; Swanson, 1981). The study of Minshall and Robinson (1992) on the Yellowstone fire showed the mean substrate size decreased in first, second and third order streams as a result of increased availability of hillslope debris. They also found that streams become wider and deeper as a result of reduced vegetation in the burned watersheds. An earlier study by White and Wells (1979) in New Mexico found that small streams incised following fire, while larger streams were aggraded, due to increases in peak spring runoff.

Overall, research on land use impacts on fluvial systems has shown that peak and annual runoff and sediment yields generally increase in the years following timber harvest and forest fires. Eventually these increases return to pre-harvest and pre-fire stages (Swanson, 1981, Troendle and King, 1985). However there is great variability in the

range of the response depending on the specific watershed characteristics. Very few studies have attempted to document morphologic response using a spatial approach.

CHAPTER 3

STUDY AREA AND METHODS

Study Area

To capture the range of potential morphologic responses of fire and clear-cut impacts, a total of 60 first order streams in a burned area, a clear-cut area, and an old growth forest were compared on the Madison Plateau along the boundary of the Targhee National Forest and Yellowstone National Park (Figure 1). The Madison Plateau can be divided into three distinct land cover categories. The burned area is to the north in the Thirsty Creek watershed, the clear-cut study area is within the Split Creek watershed, and the old growth area is within the Boundary Creek watershed (Figure 2). Twenty first order streams were identified and measured within each study area (Table 1).

Elevations for the study areas range from a maximum elevation of 2500 meters (8300 feet) to minimum elevation of 2250 meters (7500 feet). The topography is low relief and consists of undulating rolling plateaus with shallow incised drainageways (Bowerman, 1995). Lodgepole pine (*Pinus contorta*) dominates the forest cover and grouse whortleberry (*Vaccinium scoparium*) dominates the forest floor. Pinegrass (*Calamagrostis rubescens*) occupies the more open stands of lodgepole pine in the study area (Despain, 1990).

The average annual precipitation for this region is 1524 millimeters (60 inches), with 73 percent occurring as snowfall from November through May. The melting

Figure 1: Map of the study area in the Greater Yellowstone Ecosystem

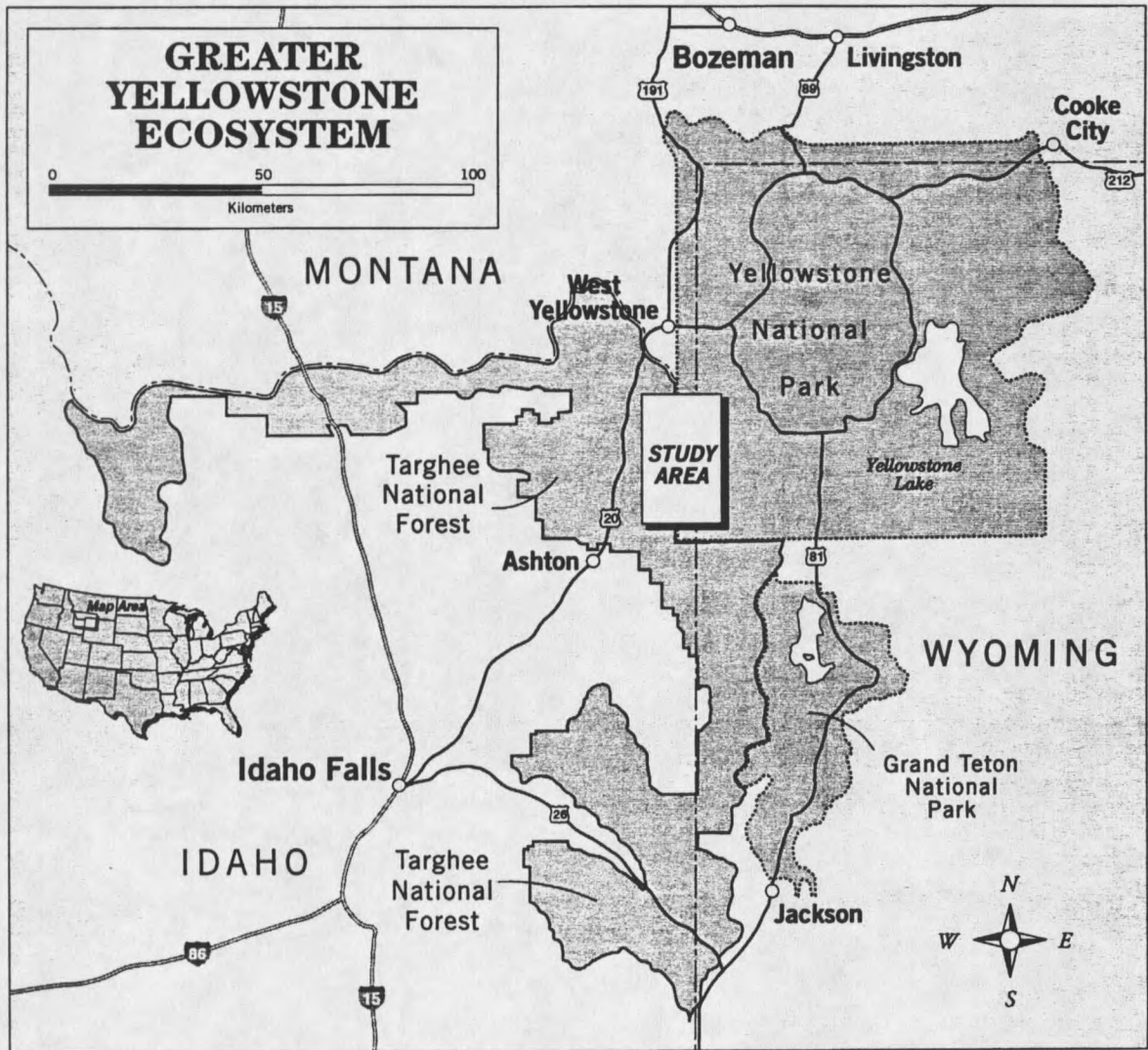


Figure 2: Map of study sight locations within study area

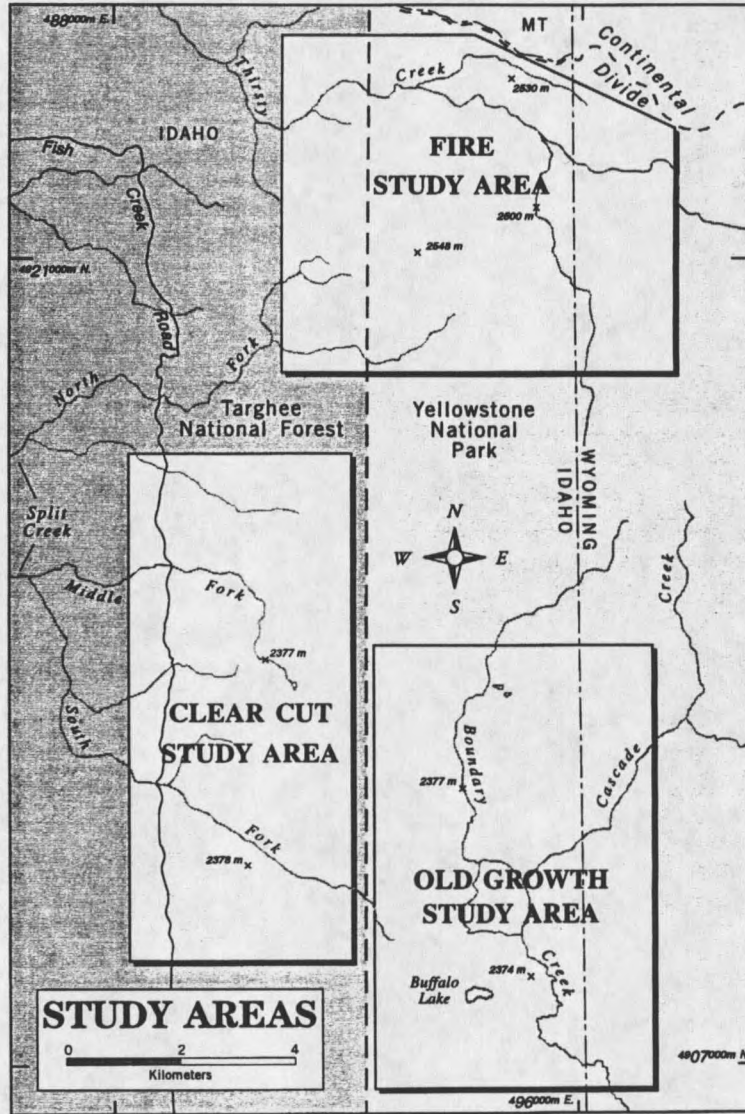


Table 1: Study site general characteristics.

		OLD GROWTH AREA	CLEAR-CUT AREA	FIRE AREA
NUMBER OF REACHES		20	20	20
ELEVATION (m)	MEAN	2370	2360	2460
	MIN	2320	2170	2420
	MAX	2400	2410	2530
	S DEV	23	55	39
VALLEY SLOPE (%)	MEAN	1.7	2.0	6.0
	MIN	0.8	0.6	2.9
	MAX	3.5	6.6	10.6
	S DEV	0.9	2.0	2.7
WATERSHED AREA (km²)	MEAN	0.6	0.3	0.3
	MIN	0.1	0.1	0.1
	MAX	3.2	3.7	5.9
	S DEV	0.8	0.8	1.3
BEDROCK CENTRAL PLATEAU MEMBER OF THE PLATEAU RHYOLITE (Qpc)		20	20	20
SURFICIAL GEOLOGY COLLUVIUM/TILL		20	20	20
STREAMS WITH FLOWING WATER (as of 26 July 1996)		16	7	0
LAST DISTURBANCE		Not Available	1960-1989*	1988

* See Appendix D

snowpack and the 254 millimeters (10 inches) of average precipitation from May through July produce significant stream flows in the spring. The Madison Plateau SNOTEL site at 2360 meters (7740 feet) receives an average of 1066 millimeters (42 inches) of precipitation (29-year average) while the Black Bear SNOTEL site at 2500 meters (8200 feet) receives an average of 1524 millimeters (60 inches) of precipitation (29-year average). These SNOTEL sites are located North of study area. The expected yearly precipitation thus probably ranges from approximately 1000 to 1500 millimeters across the study area. Due to dry summer conditions and pervious substrate, most of the first order streams within the research area are ephemeral, drying up by mid to late July.

A complex sequence of volcanic and glacial events has influenced the study area (Good and Pierce, 1996). The surface geology in this area is somewhat uncertain because the extent of the Pinedale glaciation in the study area is still debated (Pierce, personal communication, 1996). The bedrock geology (USGS, 1972a) shows 70 thousand year old rhyolite flows of the central plateau member of the plateau rhyolite. This rhyolite is younger than Bull Lake tills shown on the surficial geologic map (USGS, 1972b) and must overlay any till of this age in the area. Pinedale glacial deposits have not been recognized in the area (USGS, 1972b). The surface of the flows is composed of loose sandy material that may be of weathering, colluvial or glacial origin (USGS, 1972b; Scott, 1982). No stratification has been observed. Since all the rhyolite flows are similar in composition and age and have been similarly weathered, the material in which the study reaches flow is considered uniform throughout the study area (Christiansen and Blank, 1972).

The study area contains clear-cut, burned and old growth watersheds, all within close proximity. Forest cutting on the Madison Plateau in the Targhee National Forest began in the early 1960's and ended in 1989. Over 220 million board feet of mature lodgepole pine were harvested (Jay, 1979). Clear-cut logging followed by slash burning was used on over 25,856 hectares (64,000 acres, 100 mi²) of the Madison Plateau during this period. Best management practices had not yet been implemented and clear-cutting to streamside was common. Regeneration of the harvested lands has been left to natural processes. Clear-cuts were large enough that entire watersheds of many first order streams were harvested.

The North Fork fires in the summer of 1988 burned 214,524 hectares (531,000 acres, 829 mi²) much of it in the Targhee National Forest and Yellowstone National Park boundary area. The fire was not contained until late September of that same year (Rothermal, 1994). Just south of the fire area, on the Madison Plateau and inside Yellowstone National Park, is an area of relatively undisturbed lodgepole pine over 100 years old (Figure 2) (Despain, 1990). The land cover of the area is homogenous with only three land cover types present in the 60 stream reaches.

Methods

First order streams within the three land cover study areas were selected. Watersheds were delineated using 7.5-minute USGS quadrangles, National Forest land use maps, and air photos. The first order streams were identified based on solid blue lines on the USGS maps and the Strahler (1952) classification at a 1:24,000 scale. Elevation, valley slope and watershed areas for each stream reach were determined from the topographic maps.

Stream characteristics measured for each site were bankfull width, bankfull depth, sinuosity, bank vegetation cover, and substrate composition. At each site measurements were collected within a 100-meter reach. The start point for each reach was at a random distance upstream from confluences or road crossings. In each reach, bankfull width, depth, and cross sectional area were determined at five cross sections separated by 25 meters in stream length. Bankfull stage was defined as the point where the water in the channel begins to overflow onto the flood plain and was identified using indicators outlined by Rosgen and Silvey (1996). A line level and measuring stick were used to measure the bankfull width, depth and cross sectional area for each stream cross section. This method of field measurement was simple, quick, and reproducible by field assistants.

Sinuosity was determined by dividing the 100-meter stream channel length by the straight-line length of the reach (Harrelson et al., 1994). A reach length of 100 meters was determined to be representative based on averaging 25 meter interval sinuosity readings for a 200 meter reach within each land use category. Rosgen and Silvey (1996) recommends a study reach 20 times the maximum bankfull width therefore a length of 100 meters encompasses all possibilities found in the study area. Channel slope was determined by dividing the valley slope, measured on the map, by the sinuosity, which was measured in the field.

Vegetation cover was also recorded at each reach cross section. A plot 1 meter wide by three meters long was outlined on both the left and right bank of each cross section and the percentage of bare ground, organic material, grass, forbs, shrubs, and trees (over 6 feet tall) were visually estimated using diagrams as a reference. The average of all ten plots for each reach was calculated to provide an estimate of vegetation bank cover for the reach.

The substrate composition was measured with a Wolman (1954) pebble count in one riffle in each reach. The intermediate axis ("b") for 100 particles was measured per the U.S. Forest Service Fish Habitat Standard Inventory Procedures Handbook (Overton, 1995). Only the principle investigator selected and measured pebbles to avoid differences caused by user bias (Marcus et al., 1995). A visual estimation of the Rosgen Classification (Rosgen and Silvey, 1996) was also determined for each stream reach.

Large pieces of stable woody material (six inch diameter or greater) located within the stream channel were categorized as either single or aggregates and their frequency documented (Overton, 1995). A soil sample was taken from the right bank of the 50 meter (center) cross section to determine the bank soil texture. Percent sand, silt, and clay present in each soil sample was determined using a hydrometer and procedures as outlined by Klute (1986). Each stream reach was photographed and tagged at the center cross section for future research.

CHAPTER 4

DATA PRESENTATION

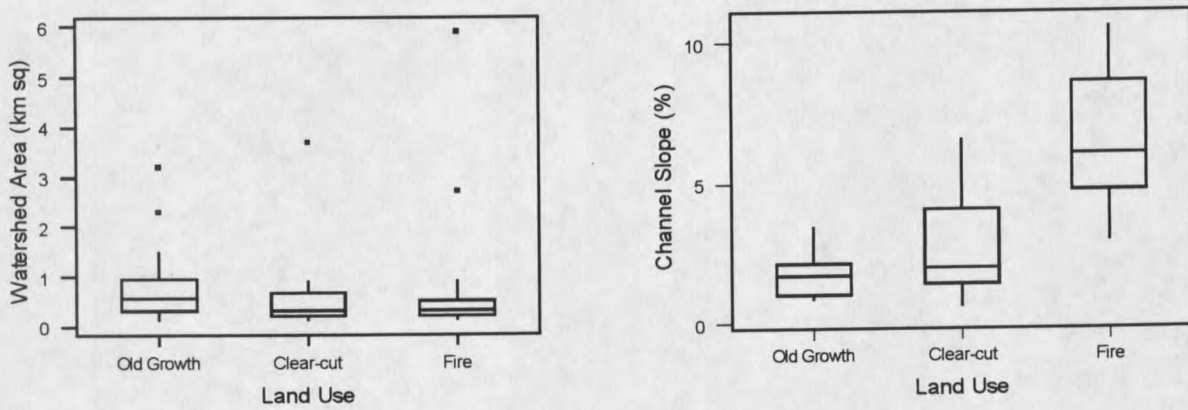
All the data for the sixty-stream study reaches are contained in Appendix A, B and C. In the following discussion, box plots summarize the data and depict differences and similarities between land use categories. Box plots (e.g., Figure 3) show the 25th and 75th percentile as the top and bottom of the box. The horizontal bar is the median. The upper and lower whiskers show the value of the 75th quartile minus the 25th quartile multiplied by 1.5 and then either added or subtracted from the 25th and 75th quartile. Outliers are shown with squares.

Watershed Variables

Watershed area and valley slopes are important parameters that can influence differences in stream morphology which are independent of land use effects (Schumm, 1977). Other watershed variables such as surface geology, vegetation type and climate were held relatively constant, through site selection. There was little variation in the watershed areas between the different land use categories (Table 1 and Figure 3). The large majority of watershed areas in all land use areas were between 0.2 km² and 0.7 km², although values ranged from 0.1 km² to 5.7 km². The effect of watershed area is not likely to be a major reason for differences in morphology between study sites.

The fire-influenced streams were in an area of higher gradient (Table 1 and Figure 3). The median channel slope values for the clear-cut area is 2.7 percent and the old

Figure 3: Box-plots of watershed area and channel slope by land use



growth is 1.7 percent, with the majority of the slopes falling between 1.4 and 2.1 percent. Median channel slope in the fire area is 6.5 percent with the majority of slopes between 4.7 and 8.6 percent. Potential effects of this higher slope on the response variables are discussed later.

Intermediate Morphologic Response Variables

Intermediate morphologic response variables such as stream bank vegetation, silt-clay ratio, amount of woody debris, and substrate size (D50) all may respond to land use, but in turn play a role in controlling the width, depth and sinuosity of the stream. In general, the old growth area had lower amounts of bare ground, lower bank silt-clay ratios, and lesser amounts of woody debris than the disturbed areas (Figure 4), while the burned and clear-cut areas were similar. The channel substrate (D50) for the clear-cut area appears to be larger than the substrate of both the fire area and the old growth area. The significance of the differences between these variables with respect to land use will be discussed later.

Channel Response Variables

The response of the stream channel to land use was measured using cross sectional area, bankfull width and depth, hydraulic radius and sinuosity (Figure 5). The only channel response variable that does not show differences between land uses is cross sectional area. The box plots indicate that the old growth streams are more sinuous and deeper than either clear-cut or burned stream areas. Bankfull width measurements

