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

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.

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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
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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; Megahan, 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

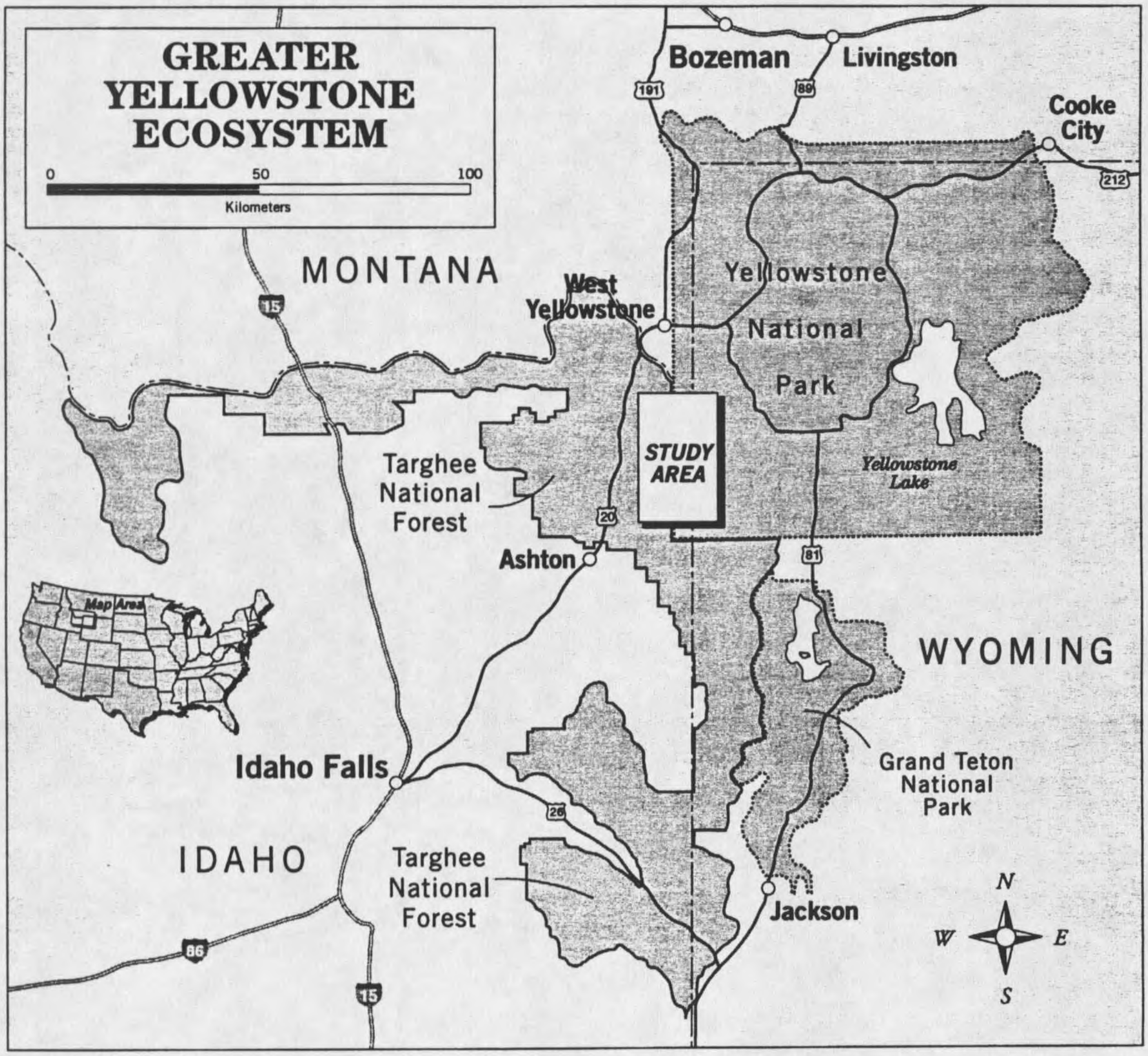


Figure 2: Map of study sight locations within study area

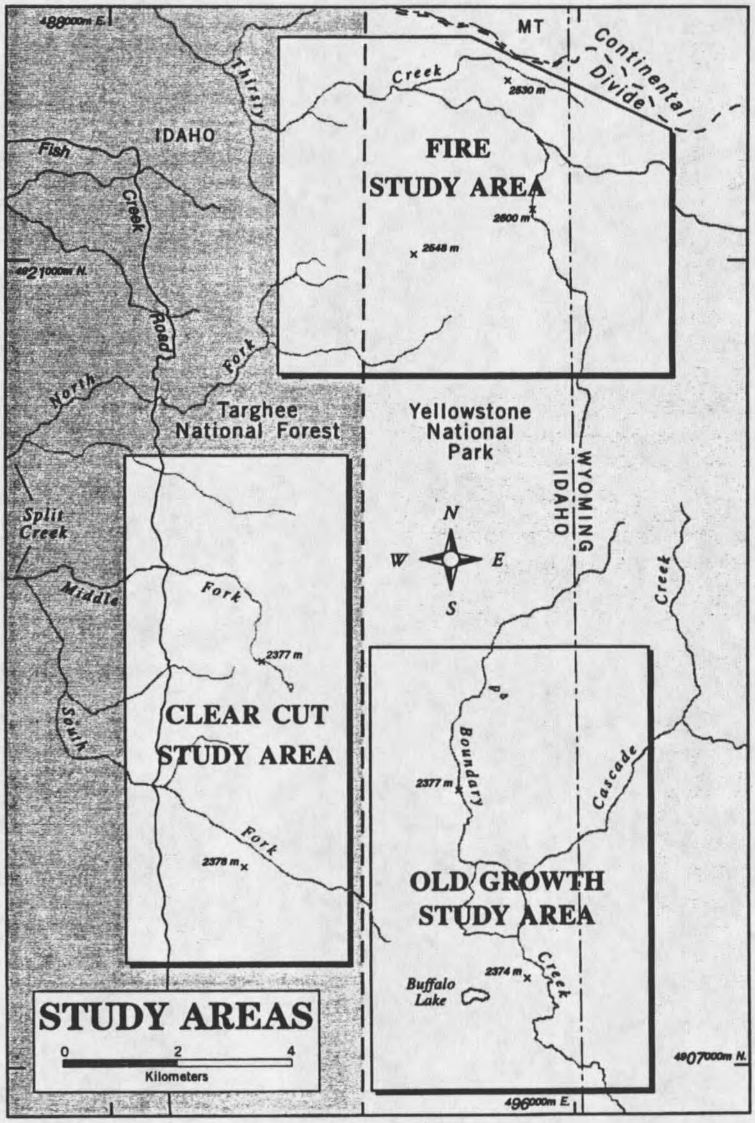


Table 1: Study site general characteristics.

		OLD GROWTH AREA	CLEAR-CUT AREA	FIRE AREA
NUMBER OF REACHES		20	20	20
ELEVATION (m)	MEAN	2370	2360	2460
	MI N	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 (km^2)	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 form 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 mi^2) 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 mi^2) 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 km^2 and 0.7 km^2, although values ranged from 0.1 km^2 to 5.7 km^2. 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

Figure 4: Box-plots of bare ground, silt-clay ratio, woody debris and substrate size by land use

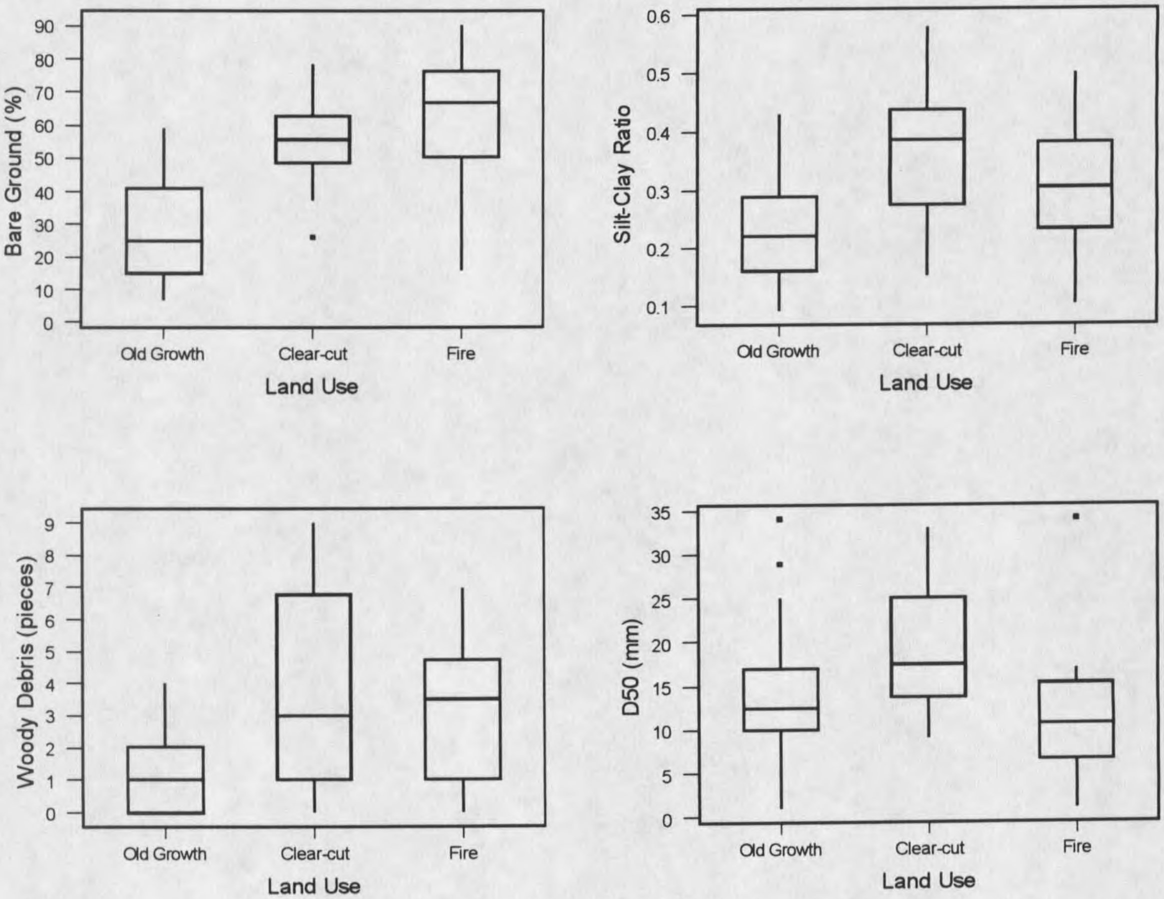
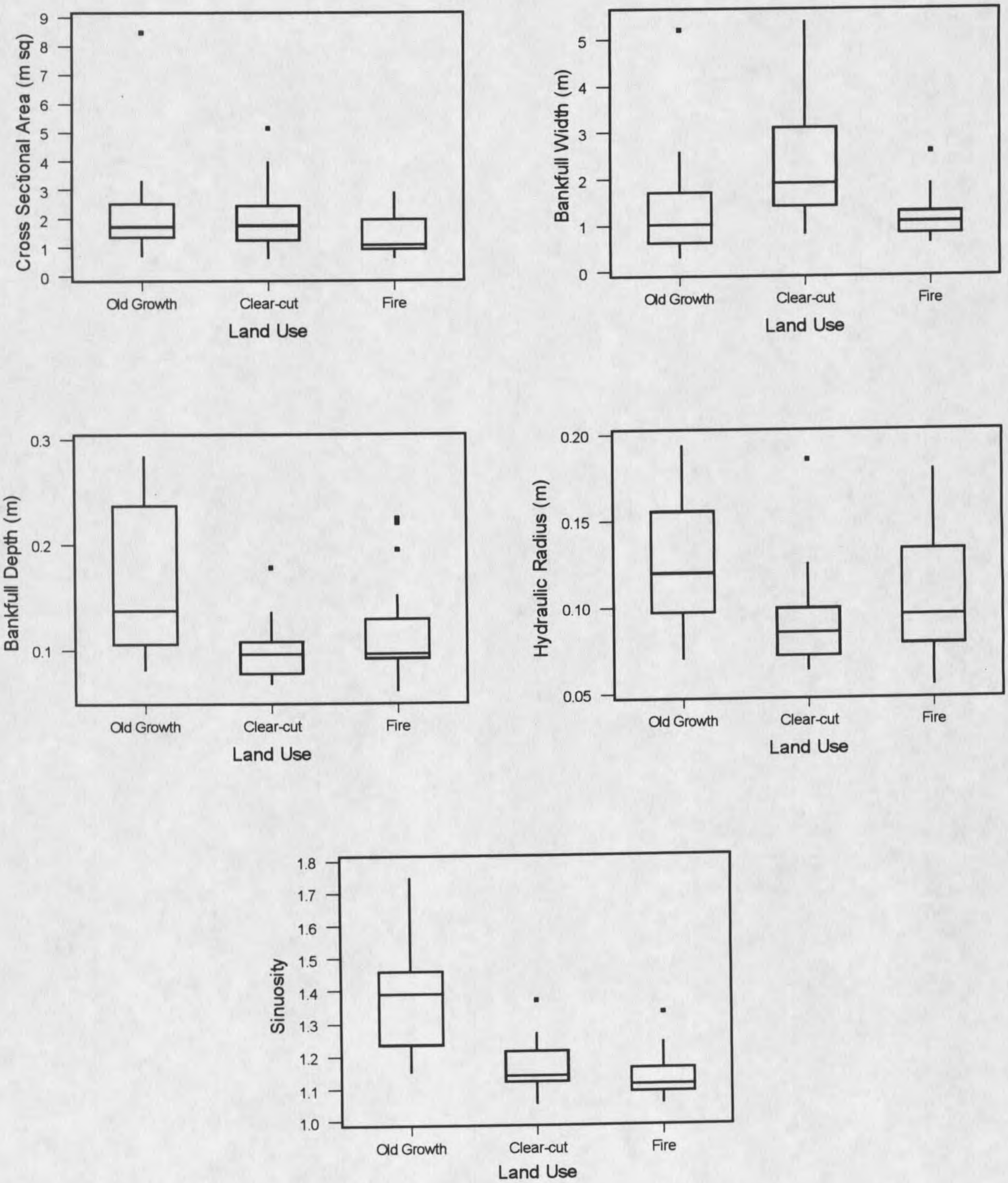


Figure 5: Box-plots of cross sectional area, bankfull width, bankfull depth, hydraulic radius and sinuosity by land use



show that the old growth streams and fire-influenced streams are narrower than the clear-cut streams. The hydraulic radii are lower for the old growth areas as compared to both clear-cut and fire areas.

CHAPTER 5

DATA ANALYSIS

Kruskal-Wallis Comparison

The box plots visually show differences in morphologic variables between the different land use areas. Kruskal-Wallis nonparametric comparison (Glass and Hopkins, 1996) was used to determine if these differences in morphology between land cover types were statistically significant (Table 2). Only watershed area and cross sectional areas do not vary between land use categories at a 0.05 level of significance. The remaining variables all vary significantly between at least two of the land use categories.

A Dunnett T test was used to determine the pairs of land use between which each morphologic variable varied significantly at the 0.05 level (Table 3). Channel slopes in clear-cuts are not significantly different from old growth slopes, but the fire slopes are significantly higher than old growth and clear-cut channel slopes. The origin of the differences in slope occurs because the location of the Northfork fire occurred on higher channel slopes, perhaps along a rhyolite flow front. The impact of this watershed variable on channel morphology will be discussed later.

Percent bare ground and woody debris in clear-cut streams and fire streams are both significantly higher than in old growth streams. There is no significant difference between clear-cut and burned areas for these variables. The silt-clay ratio is significantly higher for the clear-cut streams than old growth, but burned areas are not significantly different from the old growth or clear-cut areas. The only significant pair-wise difference

Table 2: Kruskal-Wallis comparison. An H value greater than or equal to 5.991 indicates significant variability, at the 0.05 level, between the values for morphologic variable (e.g. slope) in different land use areas. Variables that are significantly different in different land use areas at the 0.05 level are bolded.

	Test Statistic (H)	**P Value**
Watershed Variables		
Watershed Area (km^2)	*4.17*	*.124*
Channel Slope (%)	**34.65**	**.000**
Intermediate Morphologic Response Variables		
Bare Ground (%)	**28.07**	**.000**
Silt-Clay Ratio	**11.99**	**.002**
Woody Debris (pcs)	**10.14**	**.006**
Substrate Size-D50 (mm)	**14.02**	**.001**
Channel Response Variables		
Sinuosity	**29.79**	**.000**
Cross Sectional Area (m^2)	*4.49*	*.106*
Bankfull Depth (m)	**14.21**	**.001**
Bankfull Width (m)	**15.01**	**.001**
Hydraulic Radius (m)	**11.07**	**.004**

Table 3: Dunnett T test results. Significance indicated in bold type. (α=0.05)

Watershed Variables	Clear-cut vs. Old Growth	Fire vs. Old Growth	Clear-cut vs. Fire
Watershed Area (km^2)	*Not Significant*	*Not Significant*	*Not Significant*
Channel Slope (%)	*Not Significant*	**Higher**	**Lower**
Intermediate Morphologic Response Variables			
Bare Ground (%)	**Higher**	**Higher**	*Not Significant*
Silt-Clay Ratio	**Higher**	*Not Significant*	*Not Significant*
Woody Debris (pcs)	**Higher**	**Higher**	*Not Significant*
Substrate Size-D50 (mm)	*Not Significant*	*Not Significant*	**Larger**
Channel Response Variables			
Sinuosity	**Lower**	**Lower**	*Not Significant*
Cross Sectional Area (m^2)	*Not Significant*	*Not Significant*	*Not Significant*
Bankfull Depth (m)	**Shallower**	**Shallower**	*Not Significant*
Bankfull Width (m)	**Wider**	*Not Significant*	**Wider**
Hydraulic Radius (m)	**Lower**	*Not Significant*	*Not Significant*

for substrate size is that fire D50 values are significantly lower than clear-cut substrate size.

The analysis of the channel response variables indicates that the sinuosity and bankfull depths are significantly lower for streams in the clear-cut area and fire area when contrasted to old growth. The bankfull widths are significantly higher in the clear-cut area. The hydraulic radius is significantly lower in the clear-cut area than in the old growth area. Streams in the clear-cut area appear to be less sinuous, wider, shallower and have a lower hydraulic radius than old growth streams, while streams in the burn area appear to be less sinuous and shallower than old growth streams. However, caution must be used in interpreting these results, because differences in the response variables may be due to factors other than land use, as discussed in the following sections.

Scatter-Plot Analysis

The analysis of variance indicates that statistically significant differences exist between morphologic variables in different land use categories. Examination of the relationship between the watershed control variables (watershed area, channel slope and land use) and the response variables (cross sectional area, bankfull width and depth, hydraulic radius, and sinuosity) is necessary to understand the degrees to which these variations can be attributed to a specific cause. The relative differences in morphology between streams in different land cover areas can only be directly attributed to land use if all other independent variables such as channel slope, watershed area, geology topography and climate are held constant. However, if the independent variables vary significantly between study areas, the effect of land use will be more difficult to detect. The Kruskal-

Wallis comparison demonstrates that watershed area does not vary significantly between land cover types. Therefore its effect on the response variables is probably approximately the same for all land use categories. This suggests that either channel slope and/or land use is the primary factor behind the differences in the morphologic responses of the streams. Scatter plot analysis provides a means for assessing the importance of these two factors in driving channel response.

Old Growth Streams versus Clear-cut Streams

The intermediate morphologic response variables of bank vegetation and substrate size (D50) usually increase as vegetation cover decreases due to timbering (Leopold, 1980). The vegetation removal, flasher runoff, increased splash erosion and increased erosive power in response to clear-cuts can generally be expected to drive increases in percent bare ground and channel substrate size (Beschta and Platts, 1986; Leopold et al., 1964; Platts et al., 1983; Gregory et al., 1991). These changes can in turn cause a decline in bank stability, and generate a straighter, wider, and shallower channel (Schumm, 1977). The independent variables (watershed area and channel slope) of the old growth and clear-cut areas were shown to be relatively similar by the Kruskal-Wallis comparison (Table 2) and allow a test of these expectations. This will help isolate the effects of clear-cut operations on stream response.

Channel slope is generally similar between the old growth and clear-cut areas, although there are four clear-cut reaches with values 1 percent higher than any of the old growth channel slopes. In general, however, slope does not appear to be the dominant morphologic variable, which controls the differences (Figure 6 and 7). To confirm this observation, the four clear-cut reaches with higher channel slopes were disregarded and

Figure 6: Scatter plots of substrate size, silt-clay ratio, woody debris, and bare ground by channel slope. Solid squares indicate fire streams, old growth is shown by plus signs and clear-cut is shown by open squares.

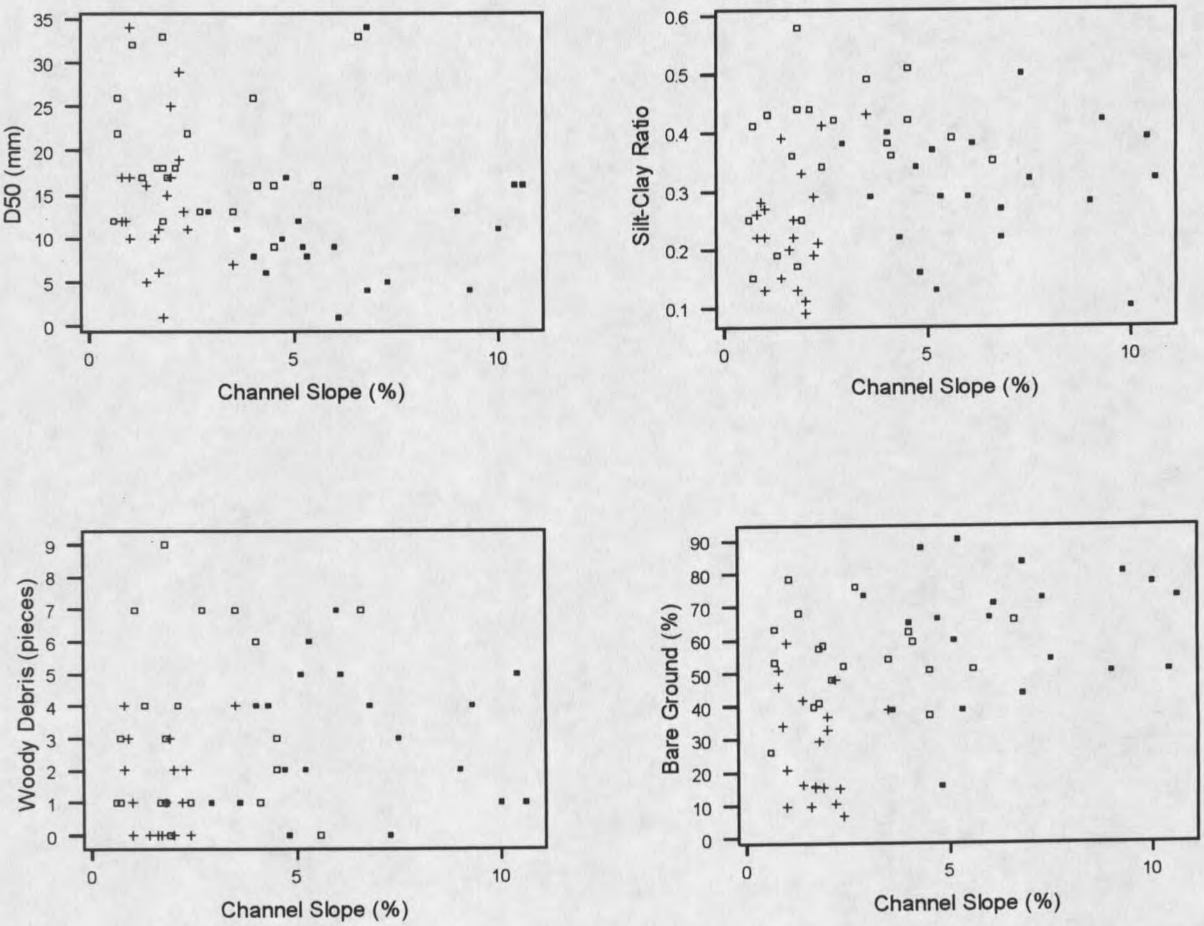
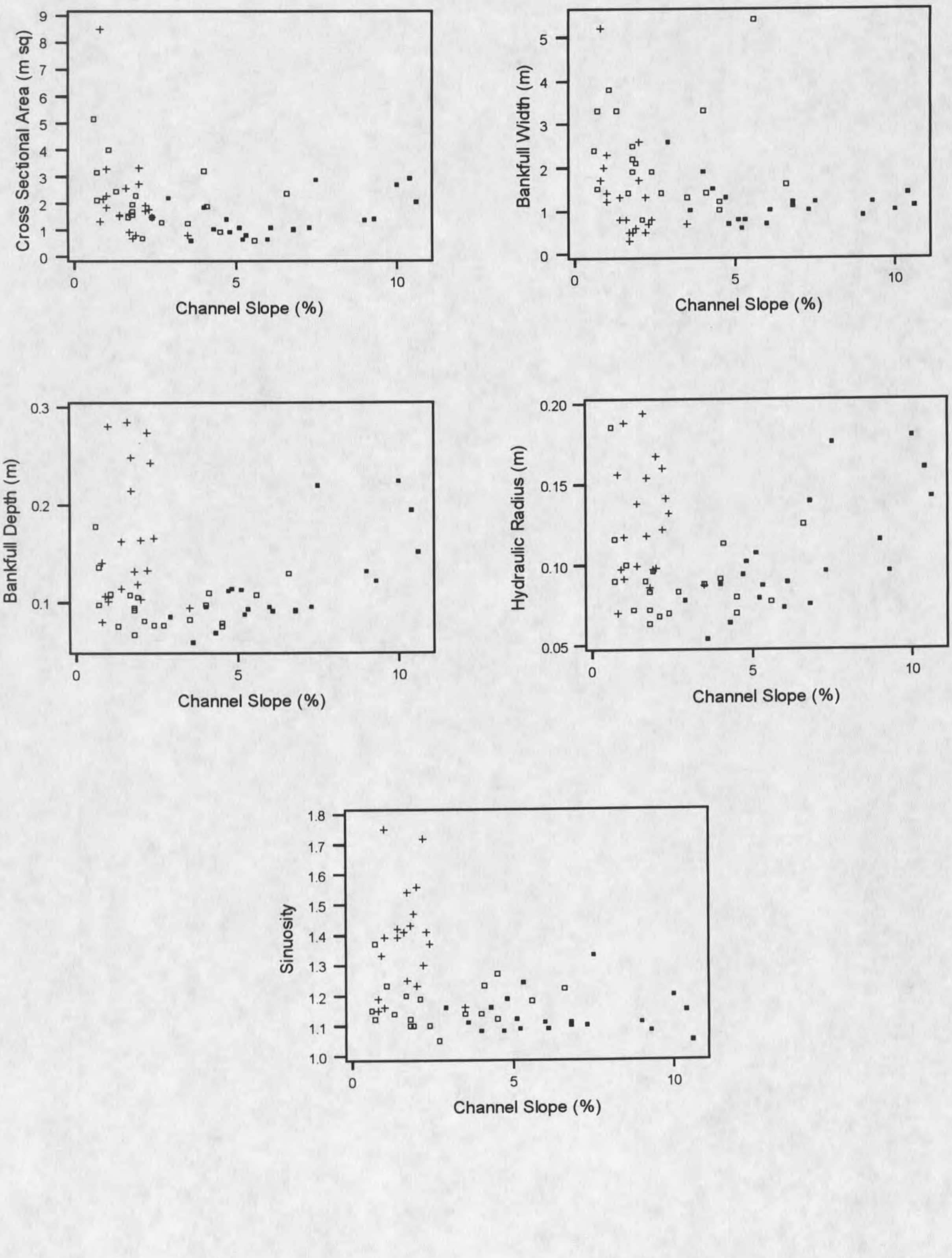


Figure 7: Scatter plots of cross sectional area, bankfull width and depth, and hydraulic radius, and sinuosity by channel slope. Solid squares indicate fire streams, old growth is shown by plus signs and clear-cut is shown by open squares.

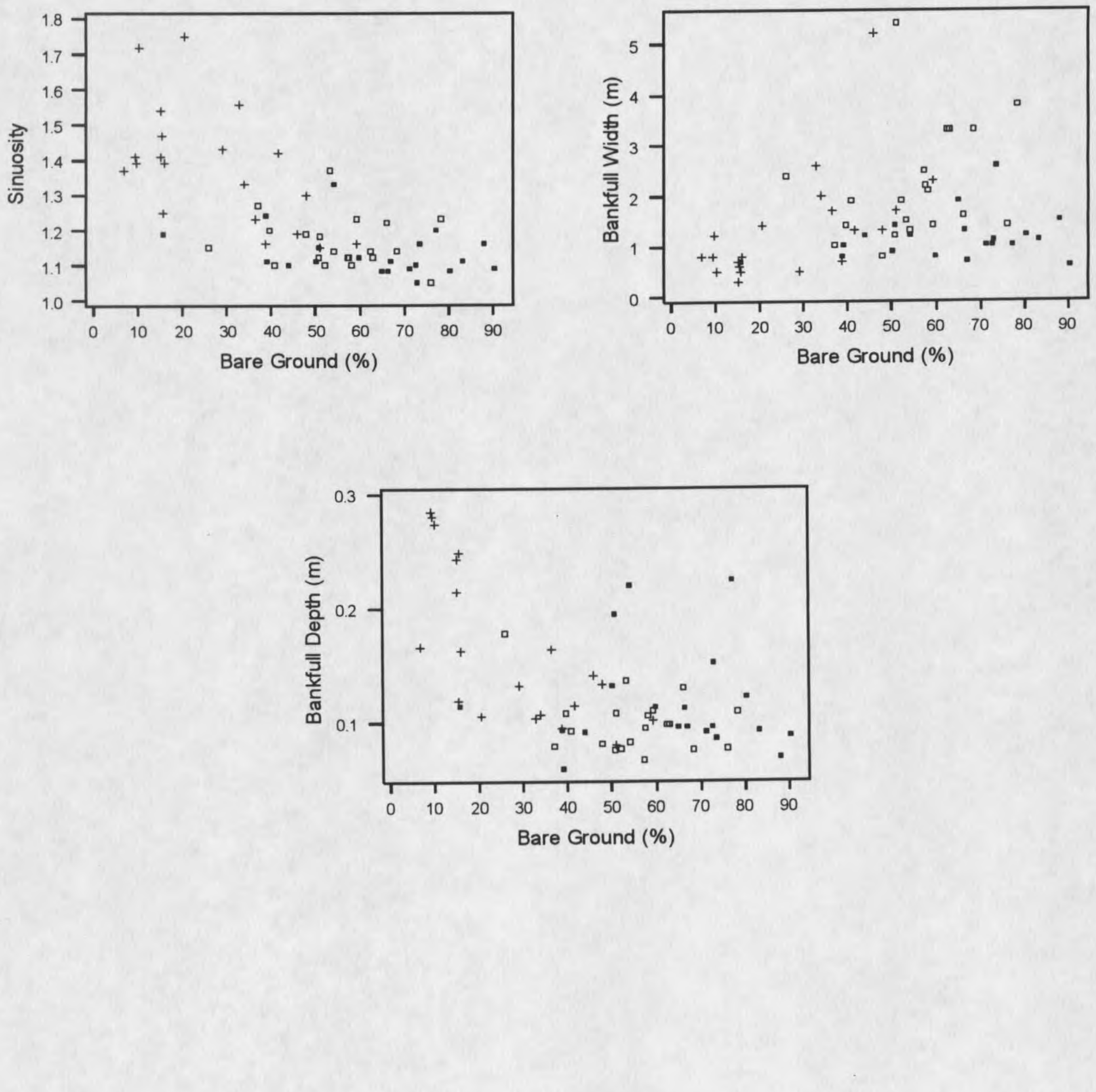


slopes with similar ranges were examined. Streams with identical slope in both the clear-cut and old growth areas show that bare ground and substrate size are higher in the clear-cut area and suggests land use might cause these differences. Clear-cut silt-clay ratios are higher than those in the old growth reaches of the same slope (Figure 7). In the absence on any recognized substrate differences, the observed silt-clay ratio difference is difficult to explain. Several possible explanations might be explored. One is that increased overbank flows in response to the flashy flows induced by clear-cuts, deposits silt on the banks (Morgorian, 1970). Alternatively, increased surface sheet flood erosion on the banks may have eroded the soil to a level with increased silt and clay due to the removal surficial layers in old growth areas. Finally, skidding may have similarly cut the soil to a depth where silt and clay contents are higher. The exact cause of this increase is not known and a detailed study of the bank composition is needed.

Given the overall similarity of slopes in the old growth area and clear-cut area, the lower sinuosity in the clear-cut area might be best explained by increases in bare ground (Figure 8). Lower sinuosities also occur at higher slopes on clear-cut plots (Figure 7). Restriction of data to similar channel slopes (channel slope less than four-percent) in both old growth and clear-cut areas suggests sinuosity in the clear-cut area is lower. The decrease in bank vegetation within the clear-cut area, which was an expected result of a disturbance, is likely to have caused instability in the stream banks and produced a straighter stream.

The shallower and wider appearance of the clear-cut streams might also be the result of this decrease in bank vegetation. Even in areas of similar channel slope (less than four percent), the bankfull width and depth results support the expected wider and shallower stream formed in response to logging (Figure 7 and 8). The scatter plot analysis

Figure 8: Scatter plots of sinuosity, bankfull width and bankfull depth by bare ground. Solid squares indicate fire streams, old growth is shown by plus signs and clear-cut is shown by open squares.



suggests that streams in the clear-cut area are responding differently, in response to the reduced vegetation on the stream banks.

Old Growth Streams versus Fire Streams

The anticipated response of streams influenced by fire is very similar to those of the clear-cut streams (Figures 6, 7 and 8). Reduced bank vegetation and higher substrate size are expected as a result of the disturbance, which in turn may drive decreased bank stability and create less sinuous, wider and shallower streams. An introduction of large woody debris resulting from disturbance would also cause decreased bank stability (Beschta and Platts, 1986) and generate shallower, less sinuous streams. Streams of similar discharge that have higher gradients are also expected, however, to be less sinuous, wider and shallower. (Schumm, 1977). Because higher slopes and fire disturbances are expected to drive stream responses in the same direction and because the fire-influenced streams were in an area of higher slopes, the determination of whether fire, channel slope, or both variables are causing the morphologic response is difficult.

In terms of intermediate response variables, bare ground and woody debris increases are expected as a result of fire. These results do occur in the study area, because the intense forest fires from 1988 consumed the under-story, creating more bare ground on fire-influenced stream banks. The fires also created more woody debris in the stream systems due to the large number of dead and dying trees falling into the stream channel (Table 2, Figure 4).

As channel slope increases, the substrate size (D50) should increase because the stream has the ability to move larger sediment (Schumm, 1977). The opposite appears to be true for the burned streams. The fire-influenced streams have a higher channel slope, yet their substrate size (D50) is generally the same as the old growth streams (Table 2, Figure 4 and 6). The similar substrate in old growth and burned areas may be the result of increased transport and storage of fine sediments in response to fire which overwhelms slope effects, or may simply reflect the size of sediment available for transport.

Streams are shallower and less sinuous in the burn areas, but these morphologic characteristics are also typical of streams with high slopes (Figure 4 and 7). We can not separate the effects of slope from the effects of the fire disturbance.

Multivariate Analysis

Regression analysis was conducted to determine if a model could be established showing the relationships between the watershed variables and the channel response variables (Table 4). Overall, the watershed variables account for little variability in the stream response (low r^2 values). The regression analysis suggests that watershed area does explain much of the variability of cross sectional area, bankfull depth and hydraulic radius. This relationship is expected (Parrett et al., 1983). According to the regression, the land use variable is the primary influence on bankfull depth, while channel slope is the primary influence on sinuosity.

Regression was used to determine whether the intermediate morphologic response variables control morphologic response variables (Table 5). The r^2 values improved, but are still low. The interesting relationship from this analysis is the significance and relationship between bank vegetation and channel response variables. Bank vegetation is significantly correlated to all stream response variables except cross sectional area. Sinuosity appears to have the strongest relationship to the intermediate morphologic response variables with bank vegetation explaining 50 percent of the variance in sinuosity.

Table 4: Summary of multiple regression analysis of watershed variables and morphologic response variables. Significant (α=0.05) r^2 are bold.

Dependent Variable	r^2	Channel Slope		Watershed Area		Land Use	
	%	*Slope (b)*	*P Value*	*Slope (b)*	*P Value*	*Slope (b)*	*P Value*
Cross Sectional Area	16.7	0.051	0.479	0.429	**0.010**	-0.233	0.325
Bankfull Width	19.4	0.013	0.820	0.178	0.170	-0.558	**0.005**
Bankfull Depth	15.1	0.000	0.840	0.020	**0.006**	0.008	0.420
Hydraulic Radius	16.2	0.001	0.565	0.013	**0.003**	0.003	0.640
Sinuosity	19.5	-0.030	**0.001**	0.007	0.700	0.042	0.140

Table 5: Summary of multiple regression analysis of intermediate control variables and morphologic response variables. Significant (α=0.05) r^2 are bold.

Dependent Variable	r^2	D50		Silt-Clay Ratio		Woody Debris		Bare Ground	
	%	*Slope (b)*	*P Value*	*Slope (b)*	*P Value*	*Slope (b)*	*P Value*	*Slope (b)*	*P Value*
Cross Sectional Area	13.4	0.052	**0.015**	-1.460	0.316	-0.006	0.935	0.001	0.869
Bankfull Width	20.6	0.049	**0.004**	0.370	0.748	-0.047	0.451	0.016	**0.020**
Bankfull Depth	33.5	0.000	0.631	-0.075	0.187	-0.002	0.343	0.001	**0.000**
Hydraulic Radius	19.3	0.000	0.497	-0.049	0.218	-0.002	0.358	0.000	**0.038**
Sinuosity	50.0	0.000	0.914	-0.134	0.332	-0.008	0.273	-0.004	**0.000**

Although not conclusive, the regression analysis suggests that bare ground, which is a function of land use, is the most significant control on stream morphology in the study area.

CHAPTER 6

CONCLUSION

This study explores differences in stream channel characteristics between burn, timber and old growth areas. Difficulties in controlling for all independent variables effecting stream morphology, however, caused problems in isolating land use as the driving force behind morphologic differences between land use categories. In general, relative to old growth, streams in clear-cut areas are less sinuous, wider, shallower, have less bank vegetation, more woody debris, and have higher silt-clay ratios. These differences are probably the result of land use, because the driving variables of watershed area and channel slope are statistically similar in the clear-cut and old growth areas. The cause for these differences is probably related to the decrease in the amount of bank vegetation in the clear-cut areas. Streams in the burned area are less sinuous and shallower. However, it cannot be determined if land use or channel slopes, which are significantly higher in the burned watershed compared to the old growth watersheds, drive these differences.

The differences in the channel response characteristics show that when independent morphologic variables can be controlled through careful site selection, this spatial approach may be used to assess the effect of land use on stream morphology. Clearly careful attention to control of independent variables is important but difficult even in a system as apparently homogenous as the one investigated in this study. This study did not require extensive assets or a great deal of time to capture a range of variability between land use categories. The spatial approach is regionally specific in that the results of this study can only be applied to areas similar to the geology, climate and topography.

The results of this study, for example, should only be applied to the Madison Plateau and, even there, only provide relatively conclusive results for clear-cut impacts relative to old growth. This limitation makes it difficult to apply such a study over a broad landscape, although the spatial approach does provide another important tool, which can provide regional information for land managers.

The methods in this study were streamlined to enable a large data set to be collected efficiently in one field season. Validation of these methods through other studies might indicate an application of this approach over a larger spectrum of fluvial settings. This approach was not particularly effective when watershed control variables such as channel slope varied significantly between land use categories, making it difficult to assign a direct relationship between land use and stream channel morphology in dissimilar areas. The study area appeared to be an ideal location to enable the control of the independent variables, but differences were still encountered which were caused by the natural variability of the landscape. Control of the independent variables might prove even more difficult in heterogeneous locations. The ability to control independent variables is essential if this approach is to reveal significant trends by isolating one variable. The study did successfully capture the range of variability of a stream's response to varied land use when the control variables were shown to be homogenous.

Future research using this approach should be explored. The methods for this study appeared to accurately document the stream characteristics, but in the future, channel slope should be measured in the field. The role of ground water in the response of streams to land use was not documented for this study, but is worthy of further research. A detailed study on bank stability, bank vegetation, and their role with respect to stream response would also be useful.

The use of a study similar to this by land use managers could be a useful tool to improve knowledge of land use effects on streams, especially when combined with other research techniques. A spatial study combined with monitoring through time could be particularly valuable in understanding the range of stream responses to land use. The use of more advanced statistical analysis might provide a clearer portrait of which variables are driving stream response and provide a model for predicting the range of stream channel responses to land use before they occur.

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APPENDICES

APPENDIX A

OLD GROWTH DATA

	O1	O2	O3	O4	O5
GENERAL DATA					
LOCATION (utm)	924083	930083	923078	924097	924100
ELEVATION (feet)	7720	7730	7710	7810	7820
SINUOSITY	1.16	1.19	1.15	1.33	1.16
VALLEY SLOPE (%)	1.1	1.0	1.0	1.2	4.0
CHANNEL SLOPE (%)	1.0	0.8	0.8	0.9	3.5
BANKFULL WIDTH (m)	2.3	5.2	1.7	2.0	0.7
BANKFULL DEPTH(m)	0.10	0.14	0.08	0.11	0.09
HYDRAULIC RADIUS (m)	0.09	0.16	0.07	0.10	0.09
WIDTH/DEPTH RATIO	23.0	37.1	21.3	18.2	7.8
CROSS SECTIONAL AREA (m^2)	2.3	8.5	1.3	2.1	0.8
WATERSHED AREA (km^2)	0.6	0.7	0.2	0.3	0.1
RIPARIAN VEGETATION					
BARE GROUND (%)	41.8	20.7	25.9	13.1	20.7
ORGANIC (%)	16.6	23.4	18.0	17.0	17.6
GRASS (%)	30.1	24.5	28.9	32.9	18.6
SHRUB (%)	9.8	9.8	8.0	15.9	2.6
FORBS (%)	0.5	17.1	10.1	16.6	38.3
TREES (6' PLUS) (%)	0.4	2.5	2.1	0.7	1.7
WATER (%)	0.8	1.9	7.0	3.8	0.5
BED MATERIAL					
D10 (mm)	12	9	7	8	1
D50 (mm)	18	17	12	12	7
D90 (mm)	26	24	21	19	14
WOODY DEBRIS					
1 PIECE	12	5	6	12	5
2-4 PIECES	1	4	1	3	4
JAM	0	0	1	0	0
SOIL					
SAND PERCENTAGE	87	74	78	72	57
SILT PERCENTAGE	12	24	21	27	38
CLAY PERCENTAGE	1	2	1	1	5

	O6	O7	O8	O9	O10
GENERAL DATA					
LOCATION (utm)	932111	931114	943123	956120	955123
ELEVATION (feet)	7820	7840	7800	7870	7880
SINUOSITY	1.42	1.30	1.25	1.54	1.43
VALLEY SLOPE (%)	2.0	2.9	2.1	2.6	2.5
CHANNEL SLOPE (%)	1.4	2.2	1.7	1.7	1.8
BANKFULL WIDTH (m)	1.3	1.3	0.5	0.3	0.5
BANKFULL DEPTH(m)	0.11	0.13	0.25	0.21	0.13
HYDRAULIC RADIUS (m)	0.10	0.12	0.15	0.12	0.09
WIDTH/DEPTH RATIO	11.8	10.0	2.0	1.4	3.8
CROSS SECTIONAL AREA (m^2)	1.5	1.9	1.6	0.9	0.7
WATERSHED AREA (km^2)	0.4	0.4	0.7	0.4	0.5
RIPARIAN VEGETATION					
BARE GROUND (%)	24.7	31.9	0.0	1.0	6.6
ORGANIC (%)	12.9	13.3	6.7	9.8	19.8
GRASS (%)	33.6	18.6	43.2	56.1	36.9
SHRUB (%)	20.8	7.5	32.2	22.6	15.6
FORBS (%)	3.1	26.0	8.8	5.9	17.0
TREES (6' PLUS) (%)	1.0	0.0	0.0	0.1	1.2
WATER (%)	4.0	2.7	9.0	4.4	2.8
BED MATERIAL					
D10 (mm)	8	17	6	1	1
D50 (mm)	16	29	12	6	4
D90 (mm)	26	44	18	12	9
WOODY DEBRIS					
1 PIECE	3	2	5	2	6
2-4 PIECES	0	1	0	0	1
JAM	0	0	0	0	0
SOIL					
SAND PERCENTAGE	85	81	78	75	87
SILT PERCENTAGE	14	18	21	24	12
CLAY PERCENTAGE	1	1	1	1	1

	O11	O12	O13	O14	O15
GENERAL DATA					
LOCATION (utm)	956116	964106	965105	962099	959094
ELEVATION (feet)	7870	7820	7810	7770	7790
SINUOSITY	1.39	1.41	1.41	1.72	1.23
VALLEY SLOPE (%)	2.0	3.3	2.2	1.3	2.5
CHANNEL SLOPE (%)	1.4	2.3	1.6	2.2	2.0
BANKFULL WIDTH (m)	0.8	0.7	0.8	0.5	1.7
BANKFULL DEPTH(m)	0.16	0.24	0.29	0.27	0.16
HYDRAULIC RADIUS (m)	0.14	0.14	0.19	0.16	0.17
WIDTH/DEPTH RATIO	5.0	2.9	2.8	1.9	10.6
CROSS SECTIONAL AREA (m^2)	1.6	1.8	2.6	1.7	3.3
WATERSHED AREA (km^2)	0.8	1.1	2.3	1.5	0.2
RIPARIAN VEGETATION					
BARE GROUND (%)	3.7	0.0	0.0	1.4	21.3
ORGANIC (%)	8.6	11.0	8.1	9.0	15.3
GRASS (%)	45.7	47.0	15.7	50.4	26.8
SHRUB (%)	20.0	19.5	10.0	27.6	18.5
FORBS (%)	17.6	18.5	64.6	11.4	17.8
TREES (6' PLUS) (%)	0.7	0.1	0.2	0.2	0.4
WATER (%)	3.8	4.0	1.4	0.0	0.0
BED MATERIAL					
D10 (mm)	1	1	1	5	14
D50 (mm)	5	13	10	21	26
D90 (mm)	12	22	41	47	37
WOODY DEBRIS					
1 PIECE	5	7	5	2	6
2-4 PIECES	0	2	0	1	2
JAM	0	0	0	0	0
SOIL					
SAND PERCENTAGE	61	79	80	71	89
SILT PERCENTAGE	37	20	19	28	11
CLAY PERCENTAGE	2	1	1	1	0

	O16	O17	O18	O19	O20
GENERAL DATA					
LOCATION (utm)	965073	963083	949081	926069	933115
ELEVATION (feet)	7620	7670	7670	7720	7830
SINUOSITY	1.37	1.39	1.75	1.56	1.47
VALLEY SLOPE (%)	3.3	1.4	1.8	3.1	2.9
CHANNEL SLOPE (%)	2.4	1.0	1.0	2.0	1.9
BANKFULL WIDTH (m)	0.8	1.2	1.4	2.6	0.6
BANKFULL DEPTH(m)	0.17	0.28	0.11	0.10	0.12
HYDRAULIC RADIUS (m)	0.13	0.18	0.11	0.10	0.10
WIDTH/DEPTH RATIO	4.7	4.3	12.7	26.0	5.0
CROSS SECTIONAL AREA (m^2)	1.5	3.3	1.9	2.7	0.8
WATERSHED AREA (km^2)	1.0	3.2	0.3	0.6	0.3
RIPARIAN VEGETATION					
BARE GROUND (%)	0.4	3.4	19.2	21.3	8.2
ORGANIC (%)	4.7	5.3	1.4	11.4	7.2
GRASS (%)	44.8	43.2	37.2	35.1	46.1
SHRUB (%)	25.9	33.0	42.0	24.9	16.3
FORBS (%)	22.4	14.1	0.0	6.1	22.1
TREES (6' PLUS) (%)	0.0	0.0	0.0	1.2	0.2
WATER (%)	1.7	1.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	1	20	6	12	8
D50 (mm)	12	36	11	18	15
D90 (mm)	29	58	16	27	24
WOODY DEBRIS					
1 PIECE	0	3	0	4	2
2-4 PIECES	0	1	0	0	3
JAM	0	0	0	0	0
SOIL					
SAND PERCENTAGE	59	78	73	91	67
SILT PERCENTAGE	37	22	25	9	32
CLAY PERCENTAGE	4	0	2	0	1

APPENDIX B

CLEAR-CUT DATA

	C1	C2	C2	C4	C5
GENERAL DATA					
LOCATION (utm)	895137	918095	909130	912123	889166
ELEVATION (feet)	7690	7800	7880	7900	7610
SINUOSITY	1.10	1.20	1.23	1.12	1.19
VALLEY SLOPE (%)	2.0	2.0	1.3	0.8	2.5
CHANNEL SLOPE (%)	1.8	1.7	1.1	0.7	2.1
BANKFULL WIDTH (m)	1.9	1.4	3.8	3.3	0.8
BANKFULL DEPTH(m)	0.09	0.11	0.11	0.10	0.08
HYDRAULIC RADIUS (m)	0.07	0.09	0.10	0.09	0.07
WIDTH/DEPTH RATIO	21.1	12.7	34.5	33.0	10.0
CROSS SECTIONAL AREA (m^2)	1.6	1.5	4	3.2	0.7
WATERSHED AREA (km^2)	0.3	0.3	0.9	0.3	0.1
RIPARIAN VEGETATION					
BARE GROUND (%)	19.3	19.5	57.3	45.5	30.4
ORGANIC (%)	15.7	16.4	21.1	16.8	17.4
GRASS (%)	36.8	41.2	12.6	27.2	41.2
SHRUB (%)	20.3	11.6	7.4	7.8	7.0
FORBS (%)	2.0	7.0	1.4	2.1	4.0
TREES (6' PLUS) (%)	0.2	0.6	0.0	0.0	0.0
WATER (%)	5.7	3.7	0.0	0.7	0.0
BED MATERIAL					
D10 (mm)	15	1	17	12	11
D50 (mm)	33	18	32	22	19
D90 (mm)	55	32	65	42	36
WOODY DEBRIS					
1 PIECE	9	1	5	1	4
2-4 PIECES	4	1	7	2	4
JAM	5	0	0	1	0
SOIL					
SAND PERCENTAGE	83	64	57	85	56
SILT PERCENTAGE	16	32	36	13	40
CLAY PERCENTAGE	1	4	7	2	4

	C6	C7	C8	C9	C10
GENERAL DATA					
LOCATION (utm)	88169	896120	897118	909115	909113
ELEVATION (feet)	7610	7820	7820	7880	7870
SINUOSITY	1.10	1.12	1.27	1.23	1.37
VALLEY SLOPE (%)	2.6	5.0	5.7	5.0	0.9
CHANNEL SLOPE (%)	2.4	4.5	4.5	4.1	0.7
BANKFULL WIDTH (m)	1.9	1.2	1.0	1.4	1.5
BANKFULL DEPTH(m)	0.08	0.08	0.08	0.11	0.14
HYDRAULIC RADIUS (m)	0.07	0.07	0.08	0.11	0.12
WIDTH/DEPTH RATIO	23.8	15.0	12.5	12.7	10.7
CROSS SECTIONAL AREA (m^2)	1.4	0.9	0.9	1.9	2.1
WATERSHED AREA (km^2)	0.1	0.2	0.1	0.6	0.9
RIPARIAN VEGETATION					
BARE GROUND (%)	36.6	25.4	20.4	42.0	34.4
ORGANIC (%)	15.0	25.4	16.6	17.4	15.0
GRASS (%)	38.8	42.3	26.3	32.8	31.0
SHRUB (%)	7.8	2.9	5.3	5.9	13.3
FORBS (%)	1.2	4.1	0.3	1.7	2.3
TREES (6' PLUS) (%)	0.0	0.0	0.3	0.4	0.1
WATER (%)	0.6	0.0	0.0	0.0	3.9
BED MATERIAL					
D10 (mm)	12	1	9	1	14
D50 (mm)	22	9	17	16	26
D90 (mm)	43	22	32	33	62
WOODY DEBRIS					
1 PIECE	1	3	8	2	3
2-4 PIECES	1	0	3	1	0
JAM	0	2	0	0	1
SOIL					
SAND PERCENTAGE	66	58	49	64	59
SILT PERCENTAGE	29	38	45	32	39
CLAY PERCENTAGE	5	4	6	4	2

	C11	C12	C13	C14	C15
GENERAL DATA					
LOCATION (utm)	913165	912144	915148	920140	905139
ELEVATION (feet)	7770	7830	7810	7860	7840
SINUOSITY	1.14	1.14	1.12	1.05	1.22
VALLEY SLOPE (%)	4.0	1.5	2.0	2.9	8.0
CHANNEL SLOPE (%)	3.5	1.3	1.8	2.7	6.6
BANKFULL WIDTH (m)	1.3	3.3	2.2	1.4	1.6
BANKFULL DEPTH(m)	0.08	0.08	0.09	0.08	0.13
HYDRAULIC RADIUS (m)	0.09	0.07	0.08	0.08	0.13
WIDTH/DEPTH RATIO	16.3	41.3	24.4	17.5	12.3
CROSS SECTIONAL AREA (m^2)	1.3	2.5	2.0	1.3	2.3
WATERSHED AREA (km^2)	0.5	0.9	0.2	0.2	0.2
RIPARIAN VEGETATION					
BARE GROUND (%)	33.1	53.1	45.2	53.8	40.2
ORGANIC (%)	18.2	15.2	12.3	22.3	25.8
GRASS (%)	33.1	22.7	31.9	18.3	18.6
SHRUB (%)	5.9	9.0	10.0	3.1	13.9
FORBS (%)	6.2	0.0	0.6	1.3	0.9
TREES (6' PLUS) (%)	0.6	0.0	0.0	1.2	0.2
WATER (%)	2.9	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	6	8	9	1	15
D50 (mm)	14	17	18	13	33
D90 (mm)	26	34	28	27	62
WOODY DEBRIS					
1 PIECE	7	8	4	7	9
2-4 PIECES	6	3	1	5	4
JAM	1	1	0	2	3
SOIL					
SAND PERCENTAGE	59	51	81	42	58
SILT PERCENTAGE	39	45	18	50	39
CLAY PERCENTAGE	2	4	1	8	3

	C16	C17	C18	C19	C20
GENERAL DATA					
LOCATION (utm)	906141	914158	889196	883118	877028
ELEVATION (feet)	7800	7790	7570	7620	7110
SINUOSITY	1.14	1.12	1.10	1.18	1.15
VALLEY SLOPE (%)	3.5	2.0	2.1	6.6	0.7
CHANNEL SLOPE (%)	4.0	1.8	1.9	5.6	0.6
BANKFULL WIDTH (m)	3.3	2.5	2.1	5.4	2.4
BANKFULL DEPTH(m)	0.10	0.07	0.11	0.11	0.18
HYDRAULIC RADIUS (m)	0.09	0.06	0.10	0.08	0.19
WIDTH/DEPTH RATIO	33.0	35.7	19.1	49.1	13.3
CROSS SECTIONAL AREA (m^2)	3.2	1.7	2.3	0.6	5.2
WATERSHED AREA (km^2)	0.4	0.2	0.4	0.7	3.7
RIPARIAN VEGETATION					
BARE GROUND (%)	37.6	45.1	36.8	39.0	14.0
ORGANIC (%)	24.7	12.3	21.3	12.0	12.0
GRASS (%)	29.0	23.1	30.5	42.0	33.0
SHRUB (%)	7.2	17.4	9.7	6.0	40.0
FORBS (%)	1.3	1.1	0.0	1.0	0.0
TREES (6' PLUS) (%)	0.3	1.0	1.6	0.0	0.0
WATER (%)	0.0	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	12	7	10	9	7
D50 (mm)	27	13	17	16	12
D90 (mm)	60	21	30	24	17
WOODY DEBRIS					
1 PIECE	6	6	3	2	3
2-4 PIECES	4	3	0	0	0
JAM	2	0	0	0	1
SOIL					
SAND PERCENTAGE	65	62	56	75	61
SILT PERCENTAGE	31	33	39	21	36
CLAY PERCENTAGE	4	5	5	4	3

APPENDIX C

FIRE DATA

	F1	F2	F3	F4	F5
GENERAL DATA					
LOCATION (utm)	920245	921244	915255	916254	913252
ELEVATION (feet)	7960	7950	8120	8130	8040
SINUOSITY	1.08	1.11	1.05	1.10	1.08
VALLEY SLOPE (%)	10.0	7.5	11.1	8.0	4.3
CHANNEL SLOPE (%)	9.3	6.8	10.6	7.3	4.0
BANKFULL WIDTH (m)	1.2	1.1	1.1	1.0	1.9
BANKFULL DEPTH(m)	0.12	0.09	0.15	0.10	0.10
HYDRAULIC RADIUS (m)	0.10	0.14	0.14	0.10	0.09
WIDTH/DEPTH RATIO	10.0	12.2	7.3	10.0	19.0
CROSS SECTIONAL AREA (m^2)	1.4	1.0	2.0	1.1	1.8
WATERSHED AREA (km^2)	0.3	0.5	0.3	0.1	0.3
RIPARIAN VEGETATION					
BARE GROUND (%)	70.8	72.8	51.2	64.3	51.5
ORGANIC (%)	9.7	10.5	21.9	8.3	13.6
GRASS (%)	14.7	9.8	21.8	19.5	21.9
SHRUB (%)	4.8	6.9	3.2	8.0	12.9
FORBS (%)	0.0	0.0	2.0	0.0	0.0
TREES (6' PLUS) (%)	0.0	0.0	0.0	0.0	0.0
WATER (%)	0.0	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	1	1	1	1	1
D50 (mm)	6	5	17	6	8
D90 (mm)	35	18	40	17	19
WOODY DEBRIS					
1 PIECE	10	13	8	7	9
2-4 PIECES	3	3	1	0	4
JAM	1	1	0	0	0
SOIL					
SAND PERCENTAGE	58	73	68	50	60
SILT PERCENTAGE	40	26	29	40	37
CLAY PERCENTAGE	2	1	3	10	3

	F6	F7	F8	F9	F10
GENERAL DATA					
LOCATION (utm)	958204	953216	950215	949216	939236
ELEVATION (feet)	8310	8210	8250	8250	7970
SINUOSITY	1.11	1.10	1.19	1.12	1.11
VALLEY SLOPE (%)	4.0	7.5	5.7	5.7	10.0
CHANNEL SLOPE (%)	3.6	6.8	4.8	5.1	9.0
BANKFULL WIDTH (m)	1.0	1.2	0.7	0.8	0.9
BANKFULL DEPTH(m)	0.06	0.09	0.11	0.11	0.13
HYDRAULIC RADIUS (m)	0.05	0.08	0.10	0.11	0.12
WIDTH/DEPTH RATIO	16.7	13.3	6.4	7.3	6.9
CROSS SECTIONAL AREA (m^2)	0.6	1.0	0.9	1.1	1.4
WATERSHED AREA (km^2)	0.5	0.6	0.2	0.2	0.9
RIPARIAN VEGETATION					
BARE GROUND (%)	32.6	33.2	11.7	49.8	44.1
ORGANIC (%)	6.4	10.7	3.9	10.0	6.2
GRASS (%)	45.9	38.4	51.9	28.5	29.4
SHRUB (%)	15.1	17.8	32.0	11.8	20.4
FORBS (%)	0.0	0.0	0.4	0.0	0.0
TREES (6' PLUS) (%)	0.0	0.0	0.0	0.0	0.0
WATER (%)	0.0	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	1	15	10	1	4
D50 (mm)	11	34	17	13	14
D90 (mm)	23	62	30	26	24
WOODY DEBRIS					
1 PIECE	5	2	2	5	6
2-4 PIECES	1	2	0	5	2
JAM	0	2	0	0	0
SOIL					
SAND PERCENTAGE	71	78	84	63	72
SILT PERCENTAGE	28	21	15	36	27
CLAY PERCENTAGE	1	1	1	1	1

	F11	F12	F13	F14	F15
GENERAL DATA					
LOCATION (utm)	934238	934242	931242	929242	928245
ELEVATION (feet)	8100	7960	7930	7940	8170
SINUOSITY	1.24	1.15	1.33	1.20	1.09
VALLEY SLOPE (%)	6.6	12.0	10.0	12.0	6.7
CHANNEL SLOPE (%)	5.3	10.4	7.5	10.0	6.1
BANKFULL WIDTH (m)	0.8	1.4	1.2	1.0	1.0
BANKFULL DEPTH(m)	0.09	0.19	0.22	0.22	0.09
HYDRAULIC RADIUS (m)	0.09	0.16	0.18	0.18	0.09
WIDTH/DEPTH RATIO	8.9	7.4	5.5	4.5	11.1
CROSS SECTIONAL AREA (m^2)	0.8	2.9	2.9	2.7	1.1
WATERSHED AREA (km^2)	0.3	2.7	0.4	0.2	0.3
RIPARIAN VEGETATION					
BARE GROUND (%)	30.6	41.1	42.3	66.4	60.5
ORGANIC (%)	8.2	9.6	11.8	10.9	10.7
GRASS (%)	43.0	30.6	25.6	10.4	16.6
SHRUB (%)	17.8	16.9	18.7	12.3	12.2
FORBS (%)	0.4	1.8	1.6	0.0	0.0
TREES (6' PLUS) (%)	0.0	0.0	0.0	0.0	0.0
WATER (%)	0.0	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	1	6	9	1	1
D50 (mm)	8	17	17	11	3
D90 (mm)	16	32	31	28	19
WOODY DEBRIS					
1 PIECE	5	10	5	6	10
2-4 PIECES	5	4	2	0	5
JAM	1	1	1	1	0
SOIL					
SAND PERCENTAGE	71	61	68	90	62
SILT PERCENTAGE	26	37	31	9	34
CLAY PERCENTAGE	3	2	1	1	4

	F16	F17	F18	F19	F20
GENERAL DATA					
LOCATION (utm)	920246	910255	906258	913245	922242
ELEVATION (feet)	8180	8050	8040	7930	7890
SINUOSITY	1.09	1.16	1.08	1.16	1.11
VALLEY SLOPE (%)	5.7	5.0	5.0	3.3	6.7
CHANNEL SLOPE (%)	5.2	4.3	4.7	2.9	6.0
BANKFULL WIDTH (m)	0.6	1.5	1.3	2.6	0.7
BANKFULL DEPTH(m)	0.09	0.07	0.11	0.09	0.10
HYDRAULIC RADIUS (m)	0.08	0.07	0.09	0.08	0.07
WIDTH/DEPTH RATIO	6.7	21.4	11.8	28.9	7.0
CROSS SECTIONAL AREA (m^2)	0.6	1.0	1.4	2.2	0.6
WATERSHED AREA (km^2)	0.1	0.2	0.4	5.9	0.2
RIPARIAN VEGETATION					
BARE GROUND (%)	82.7	78.7	58.6	51.9	49.2
ORGANIC (%)	7.7	9.3	7.8	21.6	17.8
GRASS (%)	5.2	7.8	20.5	9.1	21.9
SHRUB (%)	2.2	2.3	3.8	16.8	10.9
FORBS (%)	2.2	2.0	9.3	0.5	0.2
TREES (6' PLUS) (%)	0.0	0.0	0.0	0.0	0.0
WATER (%)	0.0	0.0	0.0	0.0	0.0
BED MATERIAL					
D10 (mm)	1	1	1	6	1
D50 (mm)	10	6	10	14	10
D90 (mm)	20	12	23	22	17
WOODY DEBRIS					
1 PIECE	8	8	8	8	9
2-4 PIECES	2	2	1	1	7
JAM	0	2	1	0	0
SOIL					
SAND PERCENTAGE	87	78	66	62	71
SILT PERCENTAGE	12	21	32	36	28
CLAY PERCENTAGE	1	1	2	2	1

APPENDIX D

CLEAR-CUT
YEAR CUT DATA

CUT #	Year Cut	ACRES
C1	1972	?
	1989	?
	1986	?
C2	1989	14
	1989	44
	1989	51
C3	1972	25
	1980	11
	1980	19
	1973	56
	1972	43
	1973	6
	1972	22
	1980	3
C4	1973	18
	1973	56
	1973	17
	1984	17
	1980	?
C5	1982	19
	1982	19
	1982	11
	1977	?
	1977	15
	1975	14
	1977	?
C6	1979	14
	1977	?
	1979	18
	1975	12
C7	1984	6
	1973	21
C8	1986	?
	1973	36
C9	1973	32
	1973	13
C10	?	19
	?	10
	?	56

CUT #	Year Cut	ACRES
C11	?	8
	?	8
	?	29
	?	26
	?	20
	1973	19
C12	?	61
	1972	13
	1972	22
	1981	5
	1972	35
	1981	7
	1981	6
C13	1973	7
	1973	34
C14	1973	100
	1973	7
C15	?	61
	1972	30
C16	1972	26
	1980	25
	1972	34
	?	61
C17	1982	3
	1982	2
	1982	15
	1982	33
	1982	8
C18	?	?
	1969	11
	?	17
	?	16
	1974	16
	1969	19
	1974	9
	1969	12
C19	1969	33
	1980	29
C20	1969	?