Effects of wildfire on first order stream channel morphology Yellowstone National Park, USA

by Kim J Ernstrom

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
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Abstract:
The wildfires of 1988 in Yellowstone National Park have created a unique opportunity to study the effects of fire in a relatively pristine backcountry setting. These fires affected many watersheds throughout the park raising concern about the short and long-term impacts on stream ecosystems. This study examined the effects of wildfire on first-order stream channel morphology by comparing 20 stream channels located in an unburned watershed to 20 stream channels located in a watershed that experienced high intensity canopy fire. Both of these watersheds were located west of Cooke City, MT in the northeast corner of Yellowstone National Park. Variables measured included watershed area, stream gradient, bank full width, depth, sinuosity, bed material size, stream bank texture, stream bank cover, and amount of large woody debris. Stream morphology was not significantly different between unburned and burned streams nine years following the fires. Reach scale variables such as substrate size and amount of bare ground did differ significantly between the two treatments. These differences in reach scale variables did not appear to be reflected in the morphologic variables. Four possible explanations for the lack of variation between burned and unburned stream morphology are investigated. The most likely explanation is that fire did affect stream morphology initially, but recovery occurred over nine-years. A second possibility is that fire affected reach scale variables, but counter-acting processes involving substrate size and vegetative cover resulted in no net change in morphology. Finally, it is possible that the approach used in this study did not account for other reach scale variations that may influence stream morphology. The possibility that morphology was never affected by fire is discarded based on work by Robinson and Minshall (1996). Methods used in this study allowed collection of a large set of morphologic data in one field season. Techniques are efficient and reproducible by field assistants sampling in remote locations. Further studies incorporating both spatial and temporal approaches are necessary to understand the effects of fire on stream systems in mountainous environments and to make educated decisions about fire management.

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APPROVAL

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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.

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ABSTRACT

The wildfires of 1988 in Yellowstone National Park have created a unique opportunity to study the effects of fire in a relatively pristine backcountry setting. These fires affected many watersheds throughout the park raising concern about the short and long-term impacts on stream ecosystems. This study examined the effects of wildfire on first-order stream channel morphology by comparing 20 stream channels located in an unburned watershed to 20 stream channels located in a watershed that experienced high intensity canopy fire. Both of these watersheds were located west of Cooke City, MT in the northeast corner of Yellowstone National Park. Variables measured included watershed area, stream gradient, bank full width, depth, sinuosity, bed material size, stream bank texture, stream bank cover, and amount of large woody debris. Stream morphology was not significantly different between unburned and burned streams nine years following the fires. Reach scale variables such as substrate size and amount of bare ground did differ significantly between the two treatments. These differences in reach scale variables did not appear to be reflected in the morphologic variables. Four possible explanations for the lack of variation between burned and unburned stream morphology are investigated. The most likely explanation is that fire did affect stream morphology initially, but recovery occurred over nine-years. A second possibility is that fire affected reach scale variables, but counter-acting processes involving substrate size and vegetative cover resulted in no net change in morphology. Finally, it is possible that the approach used in this study did not account for other reach scale variations that may influence stream morphology. The possibility that morphology was never affected by fire is discarded based on work by Robinson and Minshall (1996). Methods used in this study allowed collection of a large set of morphologic data in one field season. Techniques are efficient and reproducible by field assistants sampling in remote locations. Further studies incorporating both spatial and temporal approaches are necessary to understand the effects of fire on stream systems in mountainous environments and to make educated decisions about fire management.

CHAPTER 1

INTRODUCTION

In 1988, fires burned over 324,000 hectares (800,000 acres) within Yellowstone National Park. These fires overran natural firebreaks such as ridge tops and river channels and in some cases burned entire watersheds. Fires affected 32 percent of the stream systems in 20 separate drainage basins throughout the park (Minshall et al., 1989). Concern about potential watershed response was raised because fires can alter soil and increase runoff and erosion (Minshall and Robinson, 1992; Ewing, 1996). Resulting changes in hydrologic regime can directly influence the geomorphic processes of stream channels, which in turn can alter fish habitat, riparian vegetation, and overall stream stability (Swanson, 1981).

Many studies have addressed the immediate effects of wildfire on runoff, soil erosion, suspended sediment, and water chemistry, but few have examined the resulting physical characteristics of the stream channel itself. As fire management on public lands changes from a policy of suppression to one in which natural fires are permitted to burn, resource managers need better information about the impacts of fire on stream morphology, critical stream habitat, and channel recovery time. The magnitude and heterogeneity of the Yellowstone fires, along with the many different stream sizes affected, provide an excellent opportunity to document stream response to wildfire after a period of nine years.

The objective of this study was to determine if there are measurable differences in stream channel morphology (bankfull width and depth, width to depth ratio, sinuosity, and substrate size) between first order streams located in a burned watershed when compared to first order channels in a unburned watershed nine years after the fires occurred.

Previous Work

Fire alters watershed processes such as overland flow, erosion, and sedimentation (Swanson, 1981). Changes in these processes can in turn affect stream channel morphologic variables such as width, depth, substrate size, and sinuosity. Most fire effects studies have focused on the short-term impacts of fire on runoff and erosion (Brown, 1972; Ewing, 1996; Rich, 1962; Robichaud and Waldrop, 1994; Tiedmann et al., 1979). Relatively few have examined longer term morphologic response of stream channels to fire.

Fire-Induced Changes in Runoff and Erosion

The most dramatic and obvious influence of fire is the reduction of vegetative cover in the watershed. The extent of the hydrologic responses associated with a loss of vegetation is generally controlled by watershed aspect, slope, soil depth, bedrock geology, fire intensity, and climatic variables such as storm frequency and intensity (Swanson, 1981; Minshall et al., 1989).

Depending on the intensity of the fire and pre-burn soil properites, soil structure can be altered, reducing infiltration and water storage capacities. Hydrophobic conditions, combined with reduced transpiration of plants and diminished rainfall interception by the canopy can dramatically increase overland flow (Robichaud and Waldrop, 1994). Studies in western Montana showed overland flow from spring snowmelt to be eight times greater in burned and logged areas than in unburned plots (Wright and Bailey, 1982). Other studies in arid environments such as New Mexico, California, and New South Wales, Australia showed runoff to be dramatically higher in intensely burned drainages than in less intensely burned and unburned basins (Tiedemann, 1979; White and Wells, 1979; Brown, 1972).

After fire, rill and sheet erosion can increase due to increases in overland flow (Swanson, 1981). Following logging and prescribed burning, erosion rates in western Montana increased from zero in unburned plots to 50 kg/ha the first year post-burn and 150 kg/ha the second year (Tiedemann, 1979). In a controlled experiment in the southern Appalachian Mountains following a prescribed fire, Robichaud and Waldrop (1994) measured soil loss 40 times greater in high intensity burn plots than in low intensity plots one day after the fire. This large difference in erosion was attributed to greater removal of organic material, exposure of soils and lower infiltration rates with high intensity fire.

Suspended sediment load increases as erosion increases (Troendle and Bevenger, 1996). Over a four year period following the 1988 Yellowstone fires, sediment yield averaged 59 metric tons/km^2 in a burned watershed compared to only 13 tons/km^2 from the unburned watershed. This contrast was attributed to removal of riparian vegetation, which destabilized the bed and banks. Ewing (1996) recorded large post-fire suspended sediment increases in the Yellowstone River for the first year following the 1988 Yellowstone fires. Suspended sediment measurements ranged from 156 percent greater than pre-burn averages in April to 42 percent greater in June and 100 percent higher in August. Many of these post-fire watershed responses are controlled by seasonal climate variation, particularly spring snowmelt and intense isolated summer thunderstorms (Swanson, 1981).

Morphologic Responses to Fire

Few studies have quantified the impacts of fires on stream morphology. To the degree that they are documented in studies, changes in morphology usually have been assessed qualitatively with statements such as, “the channel has widened” or “scouring has occurred”. The few studies that have quantified morphological response to fire have examined changes in width, depth, substrate size, and movement of woody debris up to five years following fire. Changes in these variables provide evidence of a link between fire and fluvial adjustment.

Increased discharge may scour and enlarge channels within a burned area, then deposit the eroded materials downstream, causing aggradation (Swanson, 1981). White and Wells (1979) reported that in the first year after fires in New Mexico watersheds, low-order channels (first through third) incised as the larger channels (fourth an fifth order) aggraded, sometimes doubling in width. Many of these responses were seasonally driven. For example, spring thaw instigated channel incision in the first and second order streams until mid-summer when water depth decreased and detached bars began to revegetate. During winter, snowpack prevented erosion and deposition, stabilizing the channel (White and Wells, 1979).

Similar responses were recorded over five years following the Yellowstone fires of 1988. In 1991, Blacktail Deer Creek, a burned second order stream, exhibited localized downcutting of up to one meter in some reaches and filling and braiding in others due to debris dams (Minshall and Robinson, 1992). Cache Creek, a burned third order stream, widened and shifted laterally 30 meters during the same time period. However, Rose Creek, an unburned creek in the same region, remained relatively unchanged through the five years of study (Robinson et al., 1996).

Morphologic response to fire on a much smaller temporal and spatial scale was observed in central Arizona. After an intense crown fire burned 60 acres of the Workman Creek drainage, Rich (1962) observed that the amount of deposition and erosion in the stream channel varied with the distance from the burn during the month following the fire. Channel incision occurred immediately below the burned area in the steepest part of the channel, while deposition occurred up to one mile below the burn.

Following the fires of 1988, Minshall and Robinson (1992) documented decreases in median substrate size between 1988 and 1991 in first, second, and third order streams in Yellowstone National Park. Embeddedness, the interstitial filling of coarse bed material by fine particles, increased in first order streams immediately following the fires in 1988, then doubled in third order steams in 1989, after which a decrease was recorded in 1990 and 1991. Embeddedness remained unchanged in fourth order streams until 1991 when a dramatic increase was recorded. This sequence represents a pulse of fine sediment moving through the burned drainage network over time (Minshall and Robinson, 1992).

Florsheim and others (1991) observed a decrease in substrate size in first and second order streams in the months following a wildfire in southern California. During the dry season (May-November) gravel was delivered to the stream channel through dry ravel erosion. Runoff from the first major storm mobilized this material and deposited it in the channel causing an overall decrease in substrate size. The next storm flow scoured 89 percent of the sediment deposited during the first storm. Florsheim and others (1991) concluded that when the average size of bed material is reduced by dry ravel erosion, moderate runoff events are able to move large volumes of sediment, changing stream morphology.

Following fire, spring snow-melt flows and summer storm flows can be abnormally high, mobilizing coarse woody debris and subsequently altering channel morphology. In an area burned by the 1988 Yellowstone fires, Young and Bozek (1996) tagged pieces of woody debris. In following years woody debris moved over four times as far in a burned creek than an unburned creek with comparable geology, gradient, width, drainage area, and pre-fire vegetation.

In another Yellowstone study, Minshall and Robinson (1992) interpreted changes in amount and location of coarse woody debris to be an indicator of channel instability. The number of pieces of woody debris per 50 meter reach in first through third order streams increased during the first year following the fires in 1988. Unburned streams showed no increase. Throughout the remainder of the five year study, first through third order streams located in burned watersheds showed a net loss of woody debris, suggesting that burned streams are much more physically dynamic than streams not exposed to fire.

Summary and Research Expectations

These studies illustrate that fire can alter channel morphology over the short-term depending on the extent and intensity of fire, stream size, watershed slope and variations in seasonal climate (Minshall and Robinson, 1992; Swanson, 1981). Streams in more extensively burned watersheds demonstrate greater channel change than streams draining less extensively burned watersheds (Robinson et al., 1996). Fire effects are more pronounced in headwater streams and diminish with increasing stream order because smaller catchments are often entirely burned, while larger catchments (fourth order and higher) are usually only partially burned (Minshall et al., 1989). Differences in channel morphology are the indirect result of vegetation removal. Reduction in vegetative cover causes increased runoff and erosion and decreased bank stability, which can result in increased sedimentation and mobilization of large woody debris.

Based on this research, I expect first-order streams located in burned watersheds to be wider, shallower, less sinuous, have a smaller median substrate size and have less large woody debris than first-order streams in unburned watersheds. Few studies however, have assessed the mid- to long-term impacts of fires on morphologic variables. None have documented the full range of morphologic variations (width, depth, and sinuosity) among multiple streams of the same order for a period longer than five years after burning. In addition, the time required for watershed and stream channel recovery to pre-burn conditions is not known (if it happens at all). This study is an attempt to document the morphologic response of first-order streams nine years after wildfire.

CHAPTER 2

STUDY AREA

The study area was located in the northeast corner of Yellowstone National Park along the boundary of the Gallatin National Forest in Montana and the Shoshone National Forest in Wyoming (Figure 1). Burned and unburned watersheds were compared to evaluate the morphologic response of streams to wildfire. Twenty first order streams were measured in the burned Cache Creek drainage and in the unburned Pebble Creek drainage (Figure 2). Nine additional streams with check dams installed after the fires were measured in the burned Cache Creek drainage (Figure 2). Locations of the lower end of each reach are specified in Appendix A.

Vegetation, Climate, and the 1988 Fires

Prior to the 1988 Clover-Mist Fire that affected the study area, lodgepole pine (*Pinus contorta*) dominated the forests in the study area catchments, with subalpine fir (*Abies lasiocarpa*) and engelmann spruce (*Picea engelmannii*) occupying the canyon bottoms and whitebark pine (*Pinus albicaulis*) occurring above 2600 meters (Barrett, 1994). The Clover-Mist Fire burned from 39% of the area in the lower reaches of the Cache Creek drainage to 71% in the upper reaches near Republic Pass (Robinson and Minshall, 1996) (Figure 1). High intensity canopy fire consumed the entire canopy surrounding many of the first order streams (Table 1). Trees that were only partially burned in the 1988 fire

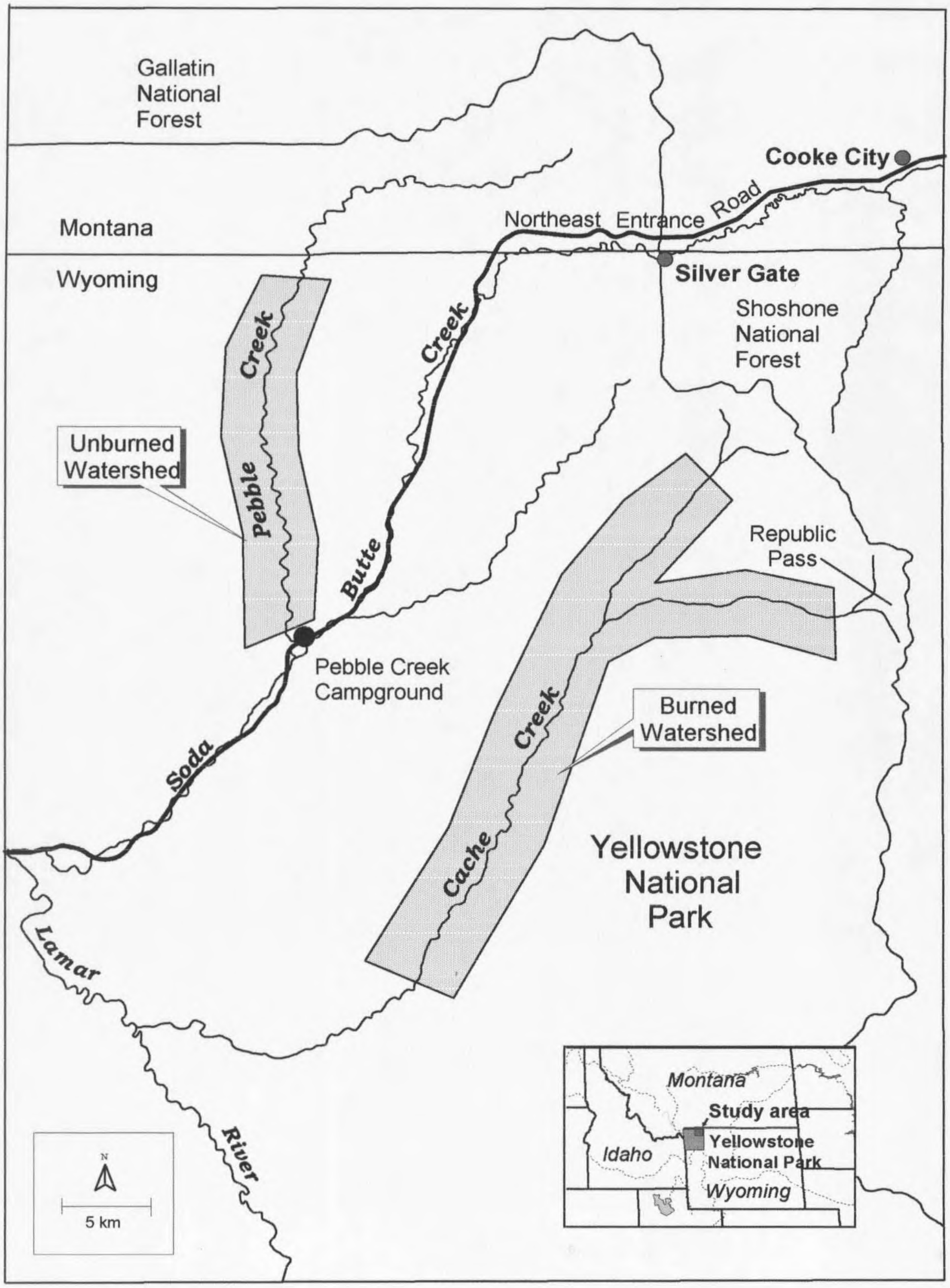

Figure 1. Study area map of Northeast Yellowstone National Park showing the unburned Pebble Creek watershed and the burned Cache Creek watershed

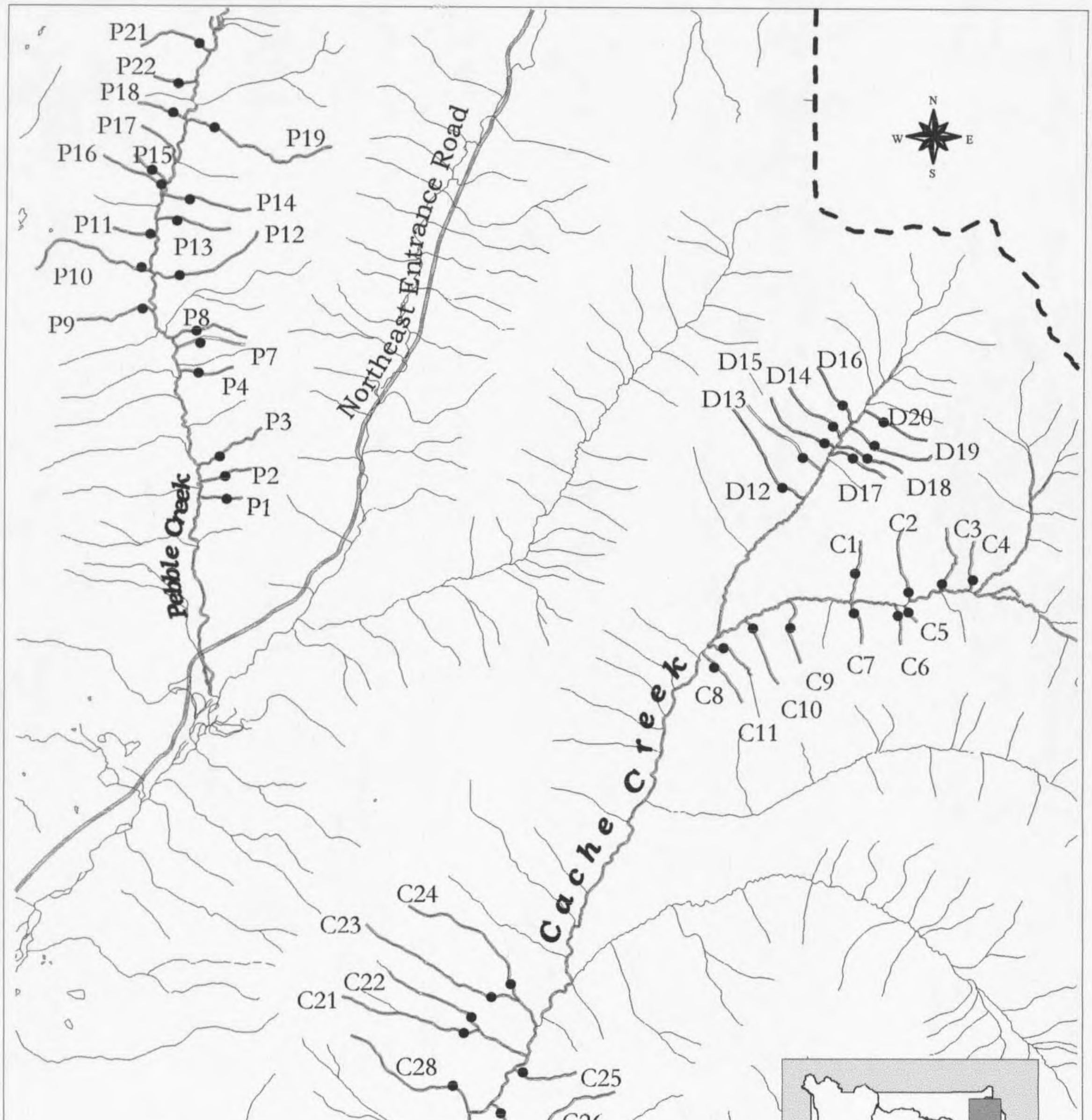

Figure 2. The unburned Pebble Creek and burned Cache Creek watersheds and 49 first-order streams measured in the study. Unburned streams are shown in green, burned streams are shown in red and dammed streams are shown in dark blue. The main stem of Pebble and Cache Creek are indicated by a light blue line. Black dots indicate the downstream end of each study reach.

Table 1. Percent of watershed burned in 1988 fires in first order streams in Cache Creek. Watershed area and percent watershed burned were calculated using a GIS and data layers provided by Yellowstone National Park.

Cache Creek (Burned Watersheds)			Cache Creek (Dammed Watersheds)		
Burned Stream #	**Watershed Area (km^2)**	**%Watershed Area Burned**	**Dammed Stream #**	**Watershed Area (km^2)**	**%Watershed Area Burned**
CH1	0.32	98	D12	0.65	88
CH2	0.60	97	D13	0.35	89
CH3	0.63	84	D14	0.26	93
CH4	0.20	100	D15	0.41	93
CH5	0.12	67	D16	0.29	78
CH6	0.50	62	D17	0.17	39
CH7	0.34	67	D18	0.23	48
CH8	0.31	73	D19	0.47	63
CH9	0.49	62	D20	0.37	84
CH10	0.37	79			
CH11	0.36	78			
CH21	1.10	31			
CH22	0.71	66			
CH23	1.00	53			
CH24	1.11	66			
CH25	0.39	47			
CH26	1.14	72			
CH27	0.43	44			
CH28	1.08	26			
CH29	0.94	80			

subsequently died, leaving a watershed that nine years later contains standing dead trees and a ground cover of grasses, forbs, and many lodgepole pine seedlings (Figure 3).

Although 17% of the Pebble Creek drainage was burned, none of the subwatersheds examined in this study were burned. All of the first order streams that were included in this study were completely surrounded by lodgepole pine dominated forests that had not burned for close to 200 years (Barrett, 1994).

Nine streams located in the upper reaches of Cache Creek had check dams installed by the Park Service as erosion control measures following the 1988 fires. Dams were constructed by felling a large tree across the streambed or by building a more elaborate structure with a stack of smaller trees supported by vertical posts (Figure 3).

Climate

In the summer, daytime temperatures in the study area typically range from 2°C to 20°C. Winter temperatures average -11°C with lows near -30°C and highs around -7°C. The thirty year mean annual precipitation in Cooke City, MT (Figure 1) is 65.9 cm (25.54 inches). On average, 509 cm (210 inches) of this precipitation falls as snow during the winter months of October through May. During the summer months convective thunderstorms provide most of the precipitation, averaging 23.6 cm (9.3 in) of rainfall. During the summer of 1994, a relatively dry summer, precipitation was received at the cooperative weather station at the Northeast Entrance of the park on only 19 days. Of these 19 rain events only four of them delivered more that 0.1 inches of rain. In contrast,