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Wildfire-Related Floods and Debris Flows in Montana in 2000 and 2001

Water-Resources Investigations Report 03-4319

U.S. Department of the Interior
U.S. Geological Survey

Front cover photograph:

Debris fan from storm event of July 2001 on tributary stream to Skalkaho Creek near Hamilton, Montana. Debris fan overlays ancient, massive debris fan on same stream. Photograph by Richard M. Jones, U.S. Department of Agriculture Forest Service.

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By Charles Parrett, Susan H. Cannon, and Kenneth L. Pierce

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Gale A. Norton, Secretary

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Multiply	By	To obtain
acre	4,047	square meter
cubic foot per second	0.028317	cubic meter per second
cubic yard	0.7646	cubic meter
foot	0.3048	meter
foot per foot	1.0	meter per meter
foot per second squared	0.3048	meter per second squared
inch	25.4	millimeter
square foot	0.09290	square meter
square inch	6.452	square centimeter
square mile	2.59	square kilometer

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), unless otherwise noted. Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27), unless otherwise noted.

Water year: The 12-month period October 1 through September 30. It is designated by the calendar year in which it ends.

<u>Acronyms used in this report:</u>

BAER	Burn Area Emergency Rehabilitation
NWS	U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service
USGS	U.S. Geological Survey

WILDFIRE-RELATED FLOODS AND DEBRIS FLOWS IN MONTANA IN 2000 AND 2001

By Charles Parrett, Susan H. Cannon, and Kenneth L. Pierce

ABSTRACT

Following extensive wildfires in summer 2000, Montana experienced flooding and debris flows in three different burned areas: (1) the Bitterroot area in southwestern Montana, (2) the Canyon Ferry area near Helena, and (3) the Ashland area in southeastern Montana.

Flooding and debris flows in the Bitterroot study area began with a large, frontal storm in September-October 2000. No precipitation data were available at sites in the burned area. Daily precipitation at one National Weather Service station near the Bitterroot burn area had a recurrence interval of about 10 years. The storm resulted in debris flows and a peak flood discharge on Little Sleeping Child Creek that had a recurrence interval of about 100 years.

Beginning in May 2001, streams in the Canyon Ferry area that flooded in response to thunderstorms were Cave Gulch, Crittenden Gulch, Magpie Creek, and Hellgate Gulch. Crittenden Gulch had a flood on May 28 with a recurrence interval estimated to be about 50 years. Small tributary streams to Magpie Creek also had debris flows. The maximum recurrence interval for recorded precipitation at U.S. Geological Survey rain gages was 5-10 years for the depth for the 15-minute duration for the July 17 storm on Crittenden Gulch. Recurrence intervals for the calculated peak discharges, based on unburned conditions, ranged from 2 years at several sites to 200 years for the July 17 flood on Crittenden Gulch.

Numerous small tributaries to Otter Creek and the Tongue River flooded in response to June and July 2001 thunderstorms in the Ashland area. The maximum recurrence interval for recorded precipitation at one U.S. Geological Survey rain gage was 100-500 years for the depth for the 5-minute duration at a site near the center of the Ashland study area. Recurrence intervals for calculated peak stream discharges, based on unburned conditions, were equal to or greater than 50 years at 16 sites and greater than 500 years at 10 sites. Three of the 10 sites with large recurrence intervals were in unburned areas.

In July 2001, thunderstorms in the Bitterroot area caused flooding on several small streams and significant debris-flow activity on small, steep tributary streams to Sleeping Child Creek. The maximum recurrence interval for recorded precipitation at U.S. Geological Survey rain gages was 10-25 years for depths for the 5-, 10-, 15-, and 30-minute durations at each site on July 15, 20, and 21. The maximum recurrence interval for peak discharges, based on unburned conditions, was 200-500 years for the peak discharges on two sites on Laird Creek on both July 20 and 21.

Calculated peak debris-flow discharge resulting from the storm of July 15 for six small tributaries to Sleeping Child Creek ranged from 1,740 to 7,860 cubic feet per second for drainage areas ranging from 0.07 to 0.41 square miles. Virtually all sediment composing the debris flows originated in the channel.

INTRODUCTION

The spring and summer of 2000 were unusually dry in most of Montana—May through August monthly precipitation totals ranged from 47 percent to 58 percent of normal at weather stations in Missoula, Helena, and Billings (National Climatic Data Center, 2000). Wildfires began in May, but fire suppression efforts, coupled with the relatively cool temperatures typical of early summer in Montana, generally prevented the significant spread of most fires until July. High July temperatures and lack of substantial precipitation created conditions conducive to fires, and by the end of July, large wildfires were burning in much of western Montana and in forested areas of eastern Montana near Ashland. The area hardest hit by wildfire was the Bitterroot study area (fig. 1), where many smaller fires merged into a large fire complex that eventually burned more than 300,000 acres. By the time most fires were extinguished or had died out in September, 40,000 acres in the Canyon Ferry study area and 60,000 acres in the Ashland study area had burned (Montana Department of Commerce, 2002) (fig. 1).

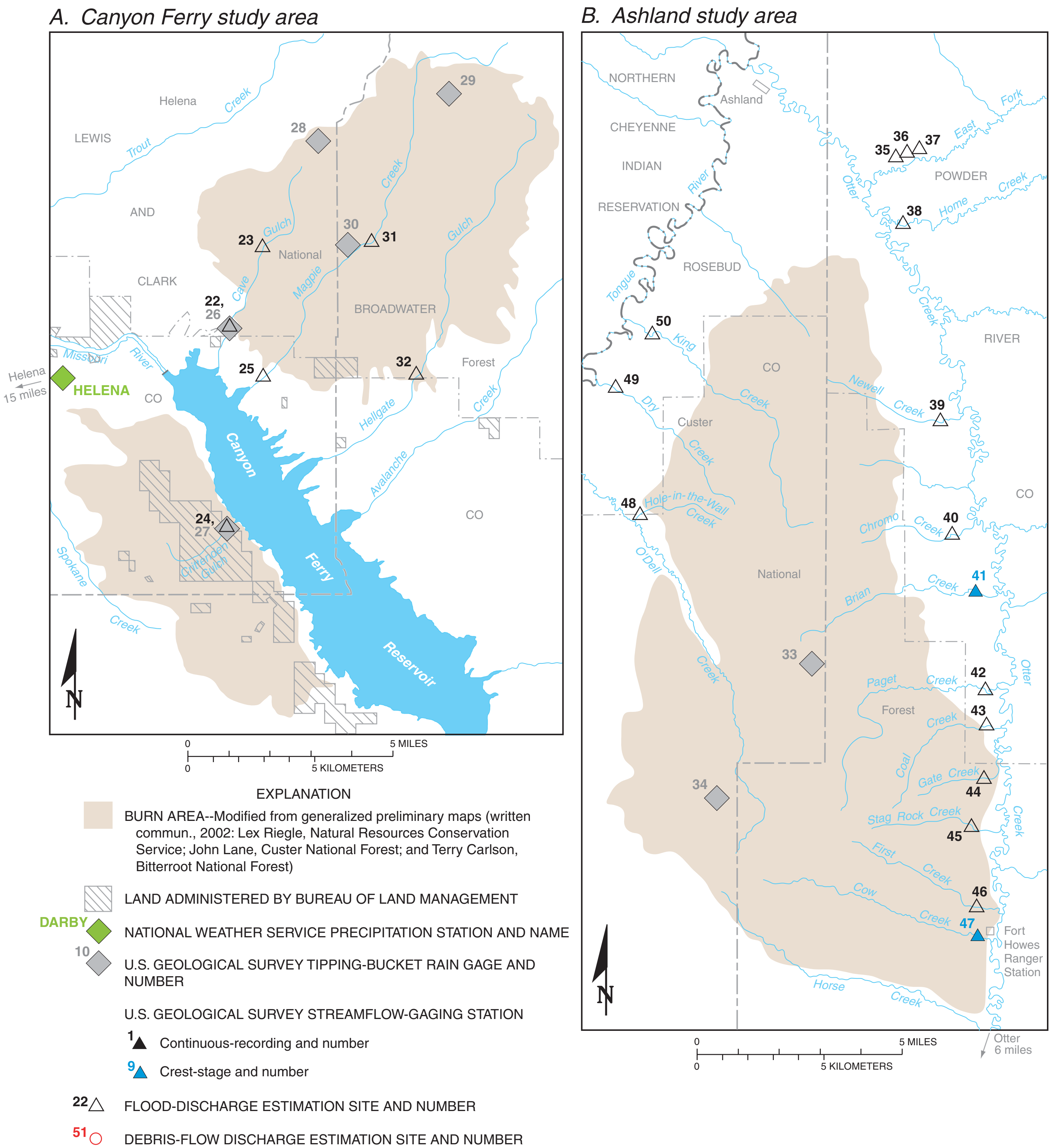
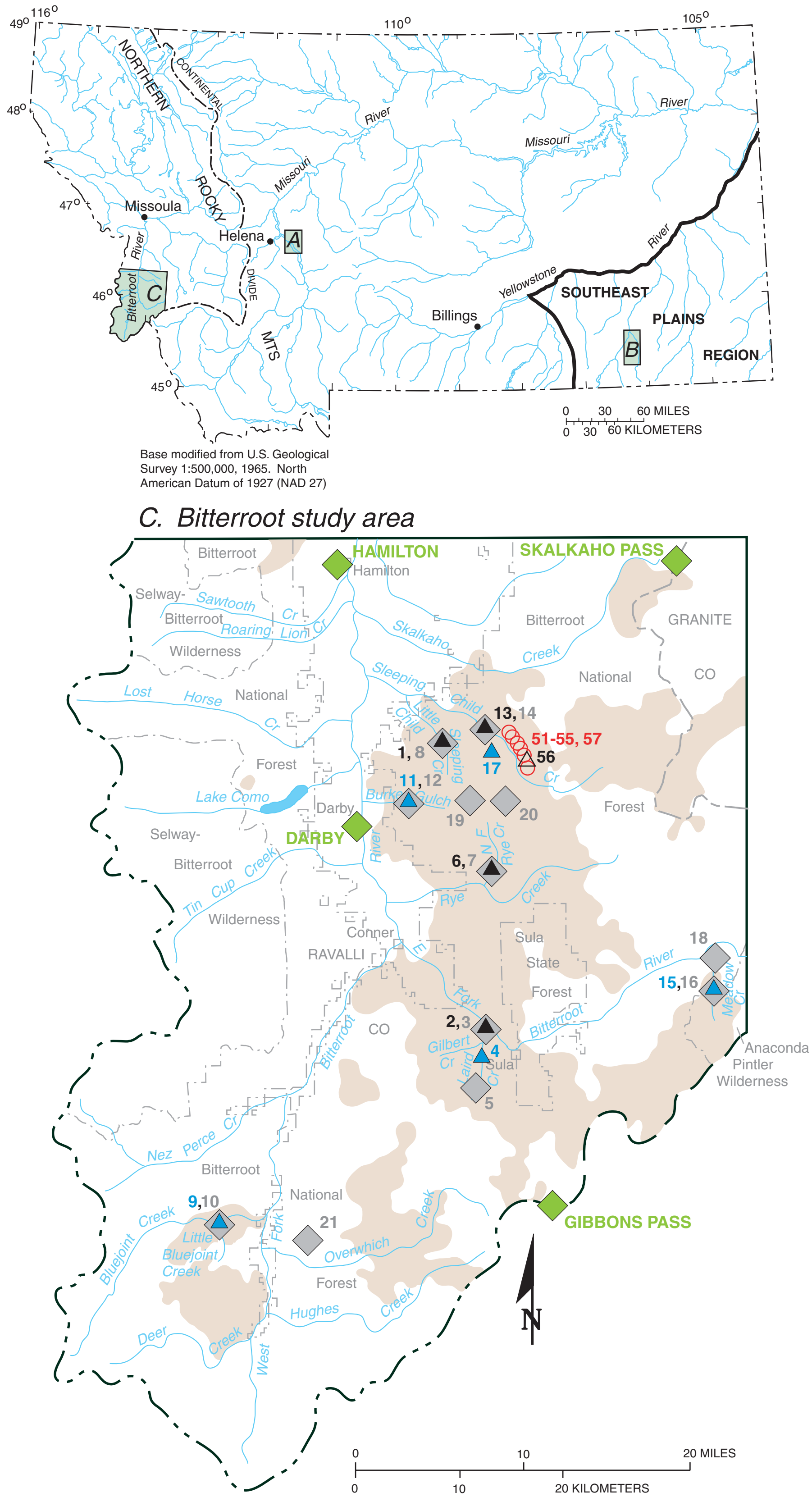


Figure 1. Location of precipitation and streamflow-gaging stations and flood



and debris-flow discharge estimation sites in three burned areas, Montana.

As concern shifted from fire suppression to landscape rehabilitation, a primary focus of governmental fire-rehabilitation teams was the potential for subsequent flooding and debris flows within burned watersheds. Floods and debris flows are a common occurrence in the western United States following fires because of the lack of vegetation and forest duff to intercept precipitation and the water-repelling characteristics of freshly burned soils. Accordingly, the Burn Area Emergency Rehabilitation (BAER) teams working in the large burn areas of Montana began planning landscape rehabilitation efforts in order to mitigate expected flood and debris-flow damage.

On September 30-October 1, 2000, a large frontal storm moved through the burned areas of the Bitterroot National Forest and caused localized flooding and debris-flow activity. In anticipation of additional flooding and debris flows, the U.S. Geological Survey (USGS), in cooperation with the Montana Department of Transportation and the U.S. Department of Agriculture Forest Service (Bitterroot National Forest), installed a continuous-recording streamflow-gaging station (site 2), several crest-stage gages, and several tipping-bucket rain gages in the Bitterroot burned areas in April and May 2001. In early summer 2001, thunderstorm activity began in many areas in Montana, including several of the burned areas. In late May 2001, flooding and debris flows occurred on several small burned watersheds in the Canyon Ferry area near Helena within the Helena National Forest, and tipping-bucket rain gages were installed in cooperation with Helena National Forest. In early June 2001, the USGS in cooperation with the Custer National Forest, also installed tipping-bucket rain gages in burned areas near Ashland in the Custer National Forest. Only several weeks later, thunderstorms in late June and early July resulted in severe flooding on small drainages in and near burned areas within the Custer National Forest. Finally, in mid to late July, after intense thunderstorms caused flooding once again in the Canyon Ferry burned area and flooding and debris flows from burned watersheds in the Bitterroot National Forest, additional streamflow-gaging stations and rain gages were installed in cooperation with Bitterroot National Forest. The storm and runoff data collected from these events presents a unique opportunity to document the hydrologic aftermath of large-scale wildfire in the Northern Rocky Mountains. Accordingly, the USGS, in cooperation with the Bitterroot, Helena, and Custer National Forests, conducted a study to describe wildfire-related floods and debris flows in Montana.

Purpose and Scope

The purpose of this report is to document the storm magnitudes and durations and subsequent flood runoff and debris flows that occurred in three different burned areas in Montana in 2000 and 2001. The areas where data were collected include: (1) the Canyon Ferry study area near the capital city of Helena, where the affected streams drain from burned areas in the Helena National Forest and forested land administered by the Bureau of Land Management, (2) the Ashland study area in southeastern Montana, where most of the affected streams drain from the burned, relatively small mountainous area within the Custer National Forest, and (3) the Bitterroot study area in southwestern Montana, where most of the affected streams drain burned areas within the Bitterroot National Forest (fig. 1).

Methods of Study

Rainfall data were compiled from National Weather Service (NWS) precipitation stations, unofficial observer reports, and USGS tipping-bucket rain gages (fig. 1). The recurrence intervals for rainfall amounts for various durations were calculated using methods developed by Miller and others (1973). Methods described by Miller and others (1973) provide estimated rain depths for specific recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. Measured rain depths in 2000 and 2001 that are between those associated with specific recurrence intervals are characterized by a range of recurrence intervals. For example, if a measured rain depth is between the value associated with a 50-year recurrence interval and the value associated with a 100-year recurrence interval, it is given a recurrence interval of 50-100 years. Peak discharges for floods were calculated using indirect-discharge determination methods developed by the USGS (Dalrymple and Benson, 1967; Hulsing, 1967; and Bodhaine, 1969). In some instances, survey data were incomplete or difficult to interpret and the calculated discharges are less reliable than those where more data or better data were available. The less reliable calculations are characterized as estimated discharges rather than calculated discharges. Peak discharges for debris flows were calculated using a simple form of the critical-flow method (Parrett, 1987) described by O'Connor and others (2001). Because of uncertainty about the applicability of the critical-flow method to debris flows, which are viscous, plastic-like flows, all calculations for peak discharges for debris flows are characterized as estimates.

The distinction between flood flows and debris flows is important because each poses different hazards that often require different mitigation strategies. Floods, for example, are often widespread throughout drainages that experience heavy rains. Flood damage often can be at least partly mitigated by flood warning and conventional flood-control structures, such as larger bridges and culverts, levees, and dams. Debris flows, on the other hand, tend to be highly localized, uniquely destructive events that may be triggered by only small amounts of rain, occur with little or no warning, and often are not amenable to conventional flood-control measures.

Floods are distinguished from debris flows primarily on the basis of the concentration and character of sediment carried in the flow. Heavily sediment-laden (hyper-concentrated) flood flows may be composed of roughly equal volumes of sediment and water, but the mixture, like pure water, continuously moves (deforms) under application of a shear stress. Debris flows, however, carry so much sediment—generally considerably greater than 50 percent by volume—that the sediment-water mixture has strength to resist deformation until some threshold value is reached. Fluids with strength, such as debris flows and freshly mixed concrete, are termed Bingham fluids, whereas fluids without strength, such as hyper-concentrated flood flows and pure water flows, are termed Newtonian fluids (Costa and Jarrett, 1981).

Flood deposits tend to be different from debris-flow deposits because of the different sediment characteristics and flow mechanics associated with the different fluid types. As described by Costa and Jarrett (1981), flood deposits, though often poorly sorted, are better sorted than debris-flow deposits. Deposits from debris flows also tend to form levees along the edges of flow that consist of very poorly sorted materials ranging from fine sand to boulders supported in a matrix of fine-grained silts, clays, and organic material. Matrix-supported deposits and levees are not characteristic of flood flows, which leave only fine-grained deposits along the flow margins and poorly sorted clasts within the channel as flows recede. These differences in deposits were used as the basis for distinguishing floods from debris flows in this report.

The recurrence intervals for peak discharges for floods were based on equations developed for ungaged sites by Parrett and Johnson (2004). These equations provide estimated discharges for specific recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years. Calculated peak discharges in 2000 and 2001 that are between those associated with specific recurrence intervals are characterized by a range of recurrence intervals. These equations were developed from long-term gaged data and do not reflect the changed hydrologic conditions resulting from wildfire. Thus, the large recurrence intervals determined for many of the flood peaks in the study areas indicate the rarity of such large floods under more normal, unburned conditions and not the rarity of such floods under the current, burned conditions. Large floods and debris flows, similar to those in 2001, may be a relatively common occurrence in the burned areas until vegetation is reestablished.

FLOOD RUNOFF AND DEBRIS FLOWS FROM A STORM IN 2000

The first substantial storm after the fires was a frontal-type storm that moved generally northeast through the Bitterroot study area on September 30 and October 1, 2000. Though fairly large in areal extent, this storm did not affect other burned areas in Montana. Twenty-four hour storm totals at four NWS gages ranged from about 1.9 inches near Skalkaho Pass east of Hamilton to less than 0.5 inch at Darby (National Climatic Data Center, 2000). The recurrence interval for the 24-hour total at Skalkaho Pass was about 10 years, while the recurrence interval for the 0.5 inch total at Darby was less than 2 years.

The storm of September 30-October 1 produced some debris flows that moved relatively small volumes of eroded material from small, burned drainages near Sula and significant flood runoff from Little Sleeping Child Creek near Hamilton. Based on a post-flood channel and high-water mark survey, the calculated peak discharge was 190 cubic feet per second for Little Sleeping Child Creek at site 1 draining 9.3 square miles of mostly burned forest. Based on regional flood-prediction equations developed by the USGS for unburned conditions, this estimated peak discharge had a recurrence interval of about 100 years. No other significant debris flows or large water flows were noted elsewhere in the Bitterroot study area as a result of the storm on September 30-October 1.

The particularly large peak flow on Little Sleeping Child Creek may have been due to more intense rainfall in this burned drainage than elsewhere in the storm area. The lack of more site-specific rainfall data or evidence of high-intensity rainfall, such as rill erosion on hillslopes, however, makes this conclusion speculative. Overall, the small amount of September 30-October 1 storm data and general lack of flood response inside and outside the burned areas indicate that the storm, while significant in terms of 24-hour rain depths, probably did not have the short periods (5-minutes to 30-minutes) of high-intensity rainfall that triggered the flooding and more substantial debris flows that occurred in the summer of 2001.

In April 2001, a continuous-recording streamflow-gaging station (site 2) and a tipping-bucket rain gage (site 3) were installed on Laird Creek near its confluence with the Bitterroot River near Sula to help collect precipitation data in the burned areas and to ensure that floods or debris flows that might occur in the burned areas would be measured and documented (fig. 1). Crest-stage streamflow gages and tipping-bucket rain gages also were installed on Laird Creek above Gilbert Creek, near Sula (sites 4 and 5), North Fork Rye Creek near Conner (sites 6 and 7), Little Sleeping Child Creek near Hamilton (sites 1 and 8), Little Bluejoint Creek near Connor (sites 9 and 10), Burke Gulch near Darby (sites 11 and 12), Sleeping Child Creek near Hamilton (sites 13 and 14), and Meadow Creek near Sula (sites 15 and 16). A crest-stage gage also was placed near the mouth of an unnamed tributary to Sleeping Child Creek (site 17), but because of its proximity to the Sleeping Child Creek gage, a tipping-bucket rain gage was not installed at site 17. A second tipping-bucket rain gage was installed near the mouth of Meadow Creek (site 18) because of the relatively large elevation difference between the crest-stage gage location and the mouth. Following storms and runoff in July 2001, the USGS replaced crest-stage gages on North Fork Rye Creek, Little Sleeping Child Creek, and Sleeping Child Creek with continuous-recording, seasonal streamflow gages and installed tipping-bucket rain gages at two additional locations in the North Fork Rye Creek basin (sites 19 and 20) and one location near Overwhich Creek (site 21).

FLOOD RUNOFF AND DEBRIS FLOWS FROM STORMS IN 2001

The following sections describe the sequential storm and runoff activity in each of three burned areas during the spring and summer of 2001. While site-specific precipitation data generally are lacking for the early storms, data are available from USGS precipitation gages for later storms. Stations and dates of occurrence of significant storms are summarized in table 1. Precipitation data and recurrence intervals for the depth accumulations for various durations during significant storms are shown in table 2. Peak-discharge (streamflow) data are summarized in table 3 while the peak debris-flow discharge data are summarized in table 4.

Canyon Ferry Area

Beginning in late May 2001, a series of thunderstorms moved generally northeast across the Canyon Ferry area near Helena. On May 27, the first storm caused flooding on Cave Gulch (site 22), which is a small (4.6 square miles drainage area), ephemeral tributary to the northeast side of Canyon Ferry Reservoir. The Cave Gulch drainage basin, which was heavily burned in 2000, also has a mine and several excavated mine-waste settling ponds near the middle of the drainage basin. Prior to the flood of May 27, streamflow in Cave Gulch near its mouth was such a rare occurrence that structures were built in the poorly defined channel. Consequently, flood discharge from the May 27 storm, although relatively small, had nowhere to go but through the structures (fig. 2).

Although no site-specific data are available for the rain intensity in the Cave Gulch drainage basin, observer reports indicated that about 0.4 inch of rain fell in about a 30-minute period. The NWS precipitation station at the Helena airport about 20 miles west of Cave Gulch reported only a trace of rain during the same period. The recurrence interval for a 30-minute precipitation depth of 0.4 inches is about 10 years.

Following the May 27 flood, channel cross sections and high-water marks at site 22 just upstream from the mouth of Cave Gulch were surveyed and the peak discharge was calculated to be 65 cubic feet per second (table 3). Because of some speculation by landowners that this flood may have, in part, resulted from the failure of some of the upstream mine-waste settling ponds, channel sections and high-water marks at a site

Table 1. U.S. Geological Survey precipitation gages in and near Montana burned areas and dates of significant rainstorms in 2001

[Symbol: --, no significant storm data]

Site number (fig. 1)	Gage number	Precipitation gage	Dates of significant rainstorms[1]
3	12343300	Laird Creek at mouth, near Sula	July 15, 20, 21
5	455129114042401	Laird Creek above Gilbert Creek, near Sula	July 15, 20, 21
7	455947114015401	North Rye Creek near Conner	July 15, 20, 22
8	460601114055001	Little Sleeping Child Creek near Hamilton	--
10	454122114015401	Little Bluejoint Creek near Conner	--
12	12344300	Burke Gulch near Darby	July 30
14	460636114001501	Sleeping Child Creek near Hamilton	July 15
16	455037113480701	Meadow Creek near Sula	--
18	455426113464901	Meadow Creek at mouth, near Sula	--
19	460201114035101	Spring Hill near Darby	--
20	4604351114002201	White Stallion Camp near Darby	--
21	454100114160601	Overwhich near Conner	--
26	463942111414801	Lower Cave Gulch near Helena	--
27	463543111413701	Crittenden Gulch near Helena	July 17, 30
28	464334111395601	Upper Cave Gulch near Helena	--
29	464359111350301	Upper Magpie Creek near Helena	July 17
30	464149111371701	Lower Magpie Creek near Helena	July 17, August 4
33	452352106144601	Upper Paget Creek near Ashland	June 30[2]
34	452030106174901	Coal Bank Creek near Ashland	June 30[2]

[1]A significant rainstorm is one that produced a peak discharge at a nearby streamflow estimation or gaged site or whose depth had a recurrence interval of 2-years or greater for a 5-, 10-, 15-, 30-, or 60-minute duration storm.
[2]Data missing for storms after July 1, 2001.

Figure 2. Flooding aftermath from the storm of May 27, 2001, in a storage building constructed in the poorly defined Cave Gulch stream channel, near Helena, Montana.

Table 2. Data for significant storms during 2001 at U.S. Geological Survey precipitation stations in Montana burned areas
[Symbol: <, less than]

Date	Upper Paget Creek (site 33)			Coal Bank Creek (site 34)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
06/30/2001	5	0.56	100-500	5	0.14	<2
	10	.75	25-50	10	.28	<2
	15	.86	25	15	.29	<2
	30	.95	10	30	.29	<2
	60	.96	5	60	.29	<2
	Daily Total	.96	<2	Daily Total	.29	<2

Date	Laird Creek at mouth (site 3)			Laird Creek above Gilbert Creek (site 5)			North Rye Creek (site 7)			Sleeping Child Creek (site 14)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
07/15/2001	5	.14	2-5	5	.09	<2	5	.22	10	5	.21	5
	10	.21	2-5	10	.17	2	10	.35	10-25	10	.38	10-25
	15	.24	2-5	15	.25	2-5	15	.44	10-25	15	.53	25
	30	.31	2	30	.31	2	30	.54	10	30	.66	10-25
	60	.31	<2	60	.35	<2	60	.62	5-10	60	.76	10
	Daily Total	.32	<2	Daily Total	.36	<2	Daily Total	.64	<2	Daily Total	.83	<2

Date	Crittenden Gulch (site 27)			Upper Magpie Creek (site 29)			Lower Magpie Creek (site 30)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
07/17/2001	5	.17	5	5	.13	2	5	.07	<2
	10	.27	5	10	.18	<2	10	.1	<2
	15	.36	5-10	15	.21	<2	15	.12	<2
	30	.41	2-5	30	.30	<2	30	.19	<2
	60	.43	2-5	60	.35	<2	60	.23	<2
	Daily Total	.70	<2	Daily Total	.58	<2	Daily Total	.39	<2

Date	Laird Creek at mouth (site 3)			Laird Creek above Gilbert Creek (site 5)			North Rye Creek (site 7)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
07/20/2001	5	.12	2	5	.21	10-25	5	.22	10
	10	.24	5	10	.35	10-25	10	.36	10-25
	15	.31	5	15	.38	10	15	.39	10-25
	30	.42	2-5	30	.42	2-5	30	.4	2-5
	60	.43	2-5	60	.43	<2	60	.41	2-5
	Daily Total	.44	<2	Daily Total	.43	<2	Daily Total	.41	<2

Table 2. Data for significant storms during 2001 at U.S. Geological Survey precipitation stations in Montana burned areas (Continued)

Date	Laird Creek at mouth (site 3)			Laird Creek above Gilbert Creek (site 5)			Sleeping Child Creek (site 14)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
07/21/2001	5	.16	5	5	.15	5	5	.19	5
	10	.31	10	10	.22	2-5	10	.35	10-25
	15	.47	10-25	15	.3	5	15	.42	10
	30	.54	10	30	.35	2-5	30	.52	5
	60	.58	5-10	60	.47	2-5	60	.55	2-5
	Daily Total	.58	<2	Daily Total	.61	<2	Daily Total	.65	<2

Date	Burke Gulch (site 12)			Crittenden Gulch (site 27)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
07/30/2001	5	.04	<2	5	.02	<2
	10	.06	<2	10	.04	<2
	15	.07	<2	15	.06	<2
	30	.09	<2	30	.12	<2
	60	.12	<2	60	.15	<2
	Daily Total	.78	<2	Daily Total	.28	<2

Date	Lower Magpie Gulch (site 30)		
	Storm duration (minutes)	Maximum rain depth (inches)	Recurrence interval (years)
08/04/2001	5	.18	5-10
	10	.28	5-10
	15	.29	2-5
	30	.33	<2
	60	.36	<2
	Daily Total	.52	<2

Table 3. Peak streamflow discharges during 2001 and recurrence intervals at streamflow-gaging stations and flood-estimation sites in and near Montana burned areas

[Symbols: >, greater than; <, less than; -- not determined]

Site number (fig. 1)	Station number	Station or stream name	Drainage area (square miles)	Date of peak discharge	Peak discharge (cubic feet per second)	Estimated recurrence interval (years)[1]
		Bitterroot Study Area				
1	460601114055001	Little Sleeping Child Creek above Spring Gulch, near Hamilton	9.3	July 30	[2]35	2
2	12343300	Laird Creek near Sula	9.3	July 20	[3]210	200-500
2	12343300	Laird Creek near Sula	9.3	July 21	[3]220	200-500
4	455129114042401	Laird Creek above Gilbert Creek, near Sula	5.1	July 20	[3]160	200-500
4	455129114042401	Laird Creek above Gilbert Creek, near Sula	5.1	July 21	[3]160	200-500
6	455947114015401	North Rye Creek near Conner	17.5	July 15	260	100
9	454122114015401	Little Bluejoint Creek near Conner	4.3	April 19	[4]100	25
11	12344300	Burke Gulch near Darby	6.5	July 30	3.3	<2
13	460636114001501	Sleeping Child Creek near Hamilton	37.0	July 15	150	<2
15	455037113480701	Meadow Creek near Sula	9.3	Late April	[4]70	<2
17	460633114001701	Unnamed tributary to Sleeping Child Creek at Hot Springs, near Hamilton	3.6	July 15	10	2
56	--	Unnamed tributary No. 7 to Sleeping Child Creek near Hamilton	1.8	July 15	[5]200	>500
		Canyon Ferry Study Area				
22	--	Cave Gulch at mouth, near Helena	4.6	May 27	65	10
23	--	Cave Gulch above mine tailings, near Helena	2.9	May 27	130	100
24	--	Crittenden Gulch at mouth, near Helena	2.3	May 28	[3]370	50
24	--	Crittenden Gulch at mouth, near Helena	2.3	July 17	[3]1,020	200
24	--	Crittenden Gulch at mouth, near Helena	2.3	July 31	[3,5]60	5-10
25	--	Magpie Creek at mouth, near Helena	25.5	May 27	[5]80	2-5
31	--	Magpie Creek above Bar Gulch, near Helena	17.4	July 17	405	50-100
32	--	Hellgate Gulch at Forest Service boundary, near Helena	9.2	July 17	[5]310	100-200
		Ashland Study Area				
35[6]	--	East Fork Otter Creek Tributary 1 near Ashland	.2	June 30	[5]980	>500
36[6]	--	East Fork Otter Creek Tributary 2 near Ashland	.1	June 30	[5]650	>500
37[6]	--	East Fork Otter Creek Tributary 3 near Ashland	1.0	June 30	[5]920	>500
38	--	Home Creek near Ashland	35.4	June 30	[5]1,000	50-100
39	--	Newell Creek near Ashland	4.3	June 30	400	50-100
40	--	Chromo Creek near Ashland	5.2	June 30	1,220	>500
41	06307720	Brian Creek near Ashland	8.0	June 30	3,200	>500
42	--	Paget Creek near Fort Howes Ranger Station, near Otter	14.0	June 30	3,500	>500
43	--	Coal Creek near Fort Howes Ranger Station, near Otter	3.1	July 10	[5]1,500	>500
44	--	Gate Creek near Fort Howes Ranger Station, near Otter	1.5	July 10	[5]1,250	>500
45	--	Stag Rock Creek near Fort Howes Ranger Station, near Otter	2.2	July 10	280	50-100
46	--	First Creek near Fort Howes Ranger Station, near Otter	3.5	July 10	520	100-200
47	06307700	Cow Creek near Fort Howes Ranger Station, near Otter	8.9	July 10	500	50-100
48	--	Hole-in-the-Wall Creek near Ashland	1.5	June 30	310	50-100
49	--	Dry Creek near Ashland	4.5	June 30	2,460	>500
50	--	King Creek near Ashland	12.4	June 30	1,920	>500

[1]Based on equations developed for ungaged sites in unburned areas by Parrett and Johnson (2004).
[2]Peak discharge from storm of September 30-October 1, 2000, was 190 cubic feet per second with recurrence interval of 100 years.
[3]Multiple peak discharges from thunderstorms.
[4]Annual peak discharge was probably due to snowmelt.
[5]Estimated discharge.
[6]Site located in unburned area.

Table 4. Peak debris-flow discharges at selected tributary sites in the Sleeping Child Creek drainage, July 15, 2001

Site number (fig. 1)	Unnamed tributary to Sleeping Child Creek	Drainage area (square miles)	Average channel slope (foot per foot)	Estimated peak discharge (cubic feet per second)
51	No. 2	0.07	0.43	1,740
52	No. 3	.09	.47	1,860
53	No. 4	.10	.46	1,930
54	No. 5	.28	.31	7,860
55	No. 6	.08	.43	3,500
57	No. 8	.41	.16	2,730

upstream from the upper-most pond (site 23) were surveyed and a peak discharge of 130 cubic feet per second was calculated (table 3). Overall, the settling ponds, some of which were partially washed out, appear to have attenuated rather than increased the flood peak. Based on regional equations developed for unburned watershed conditions, the estimated recurrence interval for the calculated flood peaks was about 100 years at the upper site and about 10 years at the lower site.

On May 28, another thunderstorm passed through Helena and the Canyon Ferry study area and caused flooding from Crittenden Gulch (site 24), a small (drainage area of 2.3 square miles) west-side tributary to Canyon Ferry Reservoir. This flood washed out an access road to several summer homes, exposed a recently constructed septic tank (fig. 3), and deposited a considerable amount of sediment in a local harbor at the mouth of the stream. The Crittenden Gulch drainage basin also was heavily burned in 2000. Although no site-specific rainfall data were available for the May 28 storm at the Crittenden Gulch site, this second storm was much more intense at the NWS station at Helena than the May 27 storm. The maximum 15-minute storm depth at the NWS site was 0.3 inch and the maximum 1-hour depth was 0.5 inch. The recurrence intervals for these depths and durations were about 25 and 50 years, respectively.

Channel cross sections and high-water marks were surveyed and the peak discharge from Crittenden Gulch at its mouth (site 24) was calculated to be 370 cubic feet per second (table 3). Based on regional flood equations developed for unburned watershed conditions, the estimated recurrence interval for the peak discharge was about 50 years.

Both the May 27 and May 28 storms caused some debris flows from small gulches draining into Magpie Creek, (drainage area of 25.5 square miles at site 25) tributary to the east side of Canyon Ferry Reservoir. Although these debris flows caused no structural damage, they did block the Magpie Creek road for several days. The material deposited on the road, though probably soupy at the time of deposit, was a hard, concrete-like matrix-supported deposit when observed several days after the event. The deposits were eroded from a burned, steep, east-facing valley wall about 400 feet above the road. The bedrock is a siltite of the Belt Supergroup of Middle Proterozoic age that erodes to small plates in a finer grained soil. The debris flows generally did not reach the Magpie Creek channel and significant flooding did not occur on Magpie Creek.

The peak flood discharge for the May 27-28 storms for Magpie Creek near the mouth (site 25) was estimated to be 80 cubic feet per second. The estimated recurrence interval for this discharge, based on unburned watershed conditions, is 2-5 years.

Following the storms in late May, five tipping-bucket rain gages were installed in burned areas (fig. 1A) to better determine future storm intensities. The rain gages were located near the mouths of Cave Gulch (site 26) and Crittenden Gulch (site 27), at a site near the headwaters of Cave Gulch (site 28), and at two sites in the Magpie Creek basin (site 29 in the upper part of the basin and site 30 near the middle of the basin).

On July 17, a thunderstorm caused significant flooding again on Crittenden Gulch and Magpie Creek

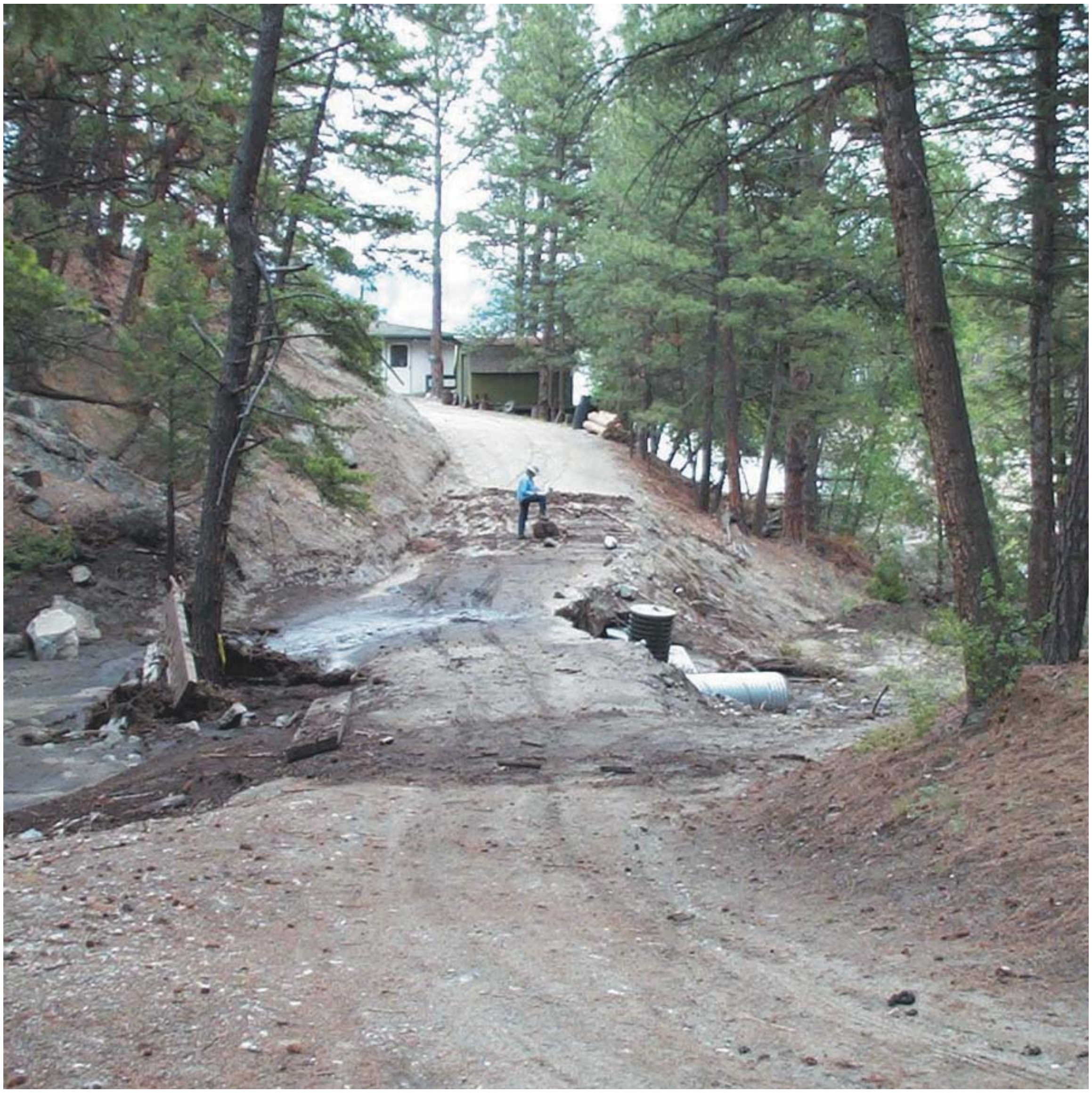


Figure 3. Flood damage on Crittenden Gulch at its mouth, near Helena, Montana. Vertical, corrugated pipe on the downstream side of the road provides access to a septic tank.

on Hellgate Gulch (site 32), a tributary to the east side of Canyon Ferry Reservoir. Rain depths at the rain-gage site in the Crittenden Gulch (site 27) drainage ranged from 0.17 inch in 5 minutes to 0.70 inch for the daily total (table 2). Rain depths at the Upper Magpie Creek gage (site 29) ranged from 0.13 inch in 5 minutes to 0.58 inch for the daily total. At the Lower Magpie Creek gage (site 30) rain depths ranged from 0.07 inch in 5 minutes to 0.39 inch for the daily total (table 2). Recurrence intervals for the rain depths ranged from <2 years for the daily total to 5-10 years for the 15-minute storm duration at the Crittenden Gulch site. Recurrence intervals for the rain depths ranged from <2 years to 2 years for all storm durations at the two gage sites in the Magpie Creek drainage.

The estimated peak discharge on Crittenden Gulch (site 24) following the July 17 storm was calculated to be 1,020 cubic feet per second (table 3). This flood caused further damage to the previously flooded access road on the west side of Canyon Ferry reservoir and completely blocked a culvert on the main road with gravel and debris. Estimated peak discharges for Magpie Creek above Bar Gulch (site 31, drainage area of 17.4 square miles) and Hellgate Gulch (site 32, drainage area of 9.2 square miles) were calculated to be 405 and 310 cubic feet per second, respectively (table 3). As indicated in table 3, estimated recurrence intervals for these flood magnitudes were 200 years for Crittenden Gulch, 50-100 years for Magpie Creek above Bar Gulch, and 100-200 years for Hellgate Gulch.

Ashland Area

On June 30, severe thunderstorms were reported in the Ashland area, and golf-ball-sized hail damaged windows in the Ashland school. Several Otter Creek and Tongue River tributaries draining burned areas within the Custer National Forest severely flooded. Severe thunderstorms and subsequent flooding occurred again in the Ashland area on July 10. Most, but not all, streams that flooded as a result of the June and July storms drained basins that were burned in 2000. Sites 35, 36, and 37 drain unburned areas (table 3).

Two tipping-bucket rain gages installed in the Ashland burned area in May collected data during the storm of June 30. One, located near the headwaters of Paget Creek (site 33, fig. 1B), recorded 0.56 inch in only 5 minutes and a storm total of 0.95 inch in 30 minutes (table 2). The second gage, located near the southwestern edge of the burned area (site 34, fig. 1B), recorded 0.14 inch in 5 minutes and a storm total of about 0.29 inch in 15 minutes. Neither gage was operable during the July 10 storm. The calculated recurrence intervals for the 5-, 10-, 15-, and 30-minute rain depths at the Paget Creek rain gage (site 33) were 100-500, 25-50, 25, and 10 years, respectively, whereas the calculated recurrence intervals for all depths at Coal Bank Creek (site 34) were less than 2 years. Based on observer reports and inspection of Doppler radar images for the storms, the National Weather Service (Steve Kuhl, National Weather Service, written communication, 2001) estimated that the maximum intensity for the June 30 storm was about 2.0-2.5 inches in 30 minutes and that the maximum intensity for the July 10 storm was about 5 inches in 2 hours in the burned area. The calculated recurrence intervals for these rainfall depths and durations exceed 500 years.

Following the storm of July 10, 16 sites (sites 35-50) were surveyed in order to calculate peak discharges (table 3). As indicated in table 3, the estimated recurrence intervals were equal to or greater than 50 years for the calculated peak discharges at the 16 sites in the Ashland area and greater than 500 years for calculated peak discharges at 10 sites. Long-term peak discharge record was available for two sites, Cow Creek near Otter (site 47, USGS station 06377700) and Brian Creek near Ashland (site 41, USGS station 062307720). The calculated peak discharge for the July 10 storm for Cow Creek was 500 cubic feet per second and had a recurrence interval of 50-100 years. The calculated peak discharge for the June 30 storm for Brian Creek was 3,200 cubic feet per second. This discharge was more than three times the previous peak (23 years of record) and more than twice the 100-year flood. The recurrence interval for the June 30 peak discharge for Brian Creek was greater than 500 years. Muddy sediment and large, woody debris deposited near the gage by the flood on Brian Creek are shown in figure 4. The thick sediment grades upward from sand at the base to finer, fire-ash and charcoal-rich silt at the top. At a site about 3.5 miles upstream from the gage, floodwaters were about 10 feet deep. Near this upper site, intense rain on hillslopes produced sheetwash that removed burned duff and fire ash, leaving a firm soil surface laced with a mesh of fine tree roots.

Figure 5 shows the relative rarity of the large floods that occurred in the Ashland study area in June and July 2001. This graph shows the maximum known peak discharges at gaged sites in the Southeast Plains Region of Montana (Parrett and Johnson, 2004) and drainage areas, together with calculated peak discharges and drainage areas for the June and July floods in the Ashland study area. Several of the calculated peak discharges in 2001 plot as high or higher than the maximum known discharges at similar-sized gaged sites (sites 35 and 36). Also shown for comparison on figure 5 is a regression line relating 100-year flood peaks (Q_{100}) to drainage area for the gaged sites. Several peak discharges for 2001 in the Ashland study area plot well above the 100-year flood regression line (sites 35, 36, 37, 40, 41, 42, 43, 44, 49, and 50). The regression line in figure 5 is based on only one explanatory variable (drainage area), whereas the regression equations developed by Parrett and Johnson (2004) are based

Figure 4. Sediment-laden floodwaters on Brian Creek near Ashland, Montana, overtopped the road and deposited a thick layer of muddy sediment (foreground) and large, woody debris (road embankment in background). Note the person standing on the culvert for scale. View is looking downstream.

on more than one explanatory variable. Consequently, one calculated peak discharge for 2001 (First Creek, site 46) plotted below the regression line, even though data in table 3 indicates that the recurrence interval is 100-200 years. The recurrence intervals shown in table 3 are considered to be more reliable than the regression line in figure 5. Finally, figure 5 distinguishes the 2001 peak-discharge sites draining burned areas from those draining unburned areas. Surprisingly, peak discharges for the three sites (sites 35, 36, and 37) draining unburned areas generally plot as high above the regression line as the highest-plotting discharges for sites draining burned areas. This result may indicate that the fire of 2000 had less effect on the 2001 flood peaks in some watersheds than did the pattern and intensity of the storms producing the runoff.

Bitterroot Area

Severe thunderstorms moved generally northeast through the Bitterroot study area on July 15, 20, and 21. The storm on July 15 produced flooding on North Rye Creek, debris flows on several tributaries to North Rye Creek, and debris flows that eroded large volumes of material from several tributaries to Sleeping Child Creek (fig. 1C). The storms on July 20 and 21 caused flooding on Laird Creek and several Laird Creek tributaries. Because of their large size, the debris flows in the Sleeping Child Creek basin will be described separately from the storms and floods.

Storm and Flood Data

Rainfall data for the July 15-21 storm periods at USGS precipitation gages on Laird Creek (sites 3 and 5), North Rye Creek (site 7), and Sleeping Child Creek (site 14) are summarized in table 2. On July 15, rain depths were relatively small at the two Laird Creek sites, ranging from 0.09-0.14 inch in 5 minutes to 0.31-0.35 inch in an hour, which was essentially the storm duration. Rain depths were greater at the North Rye Creek site, where 0.22 inch fell in 5 minutes, 0.44 inch fell in 15 minutes, and 0.62 inch fell in an hour. Rain depths at the Sleeping Child site were even greater, as

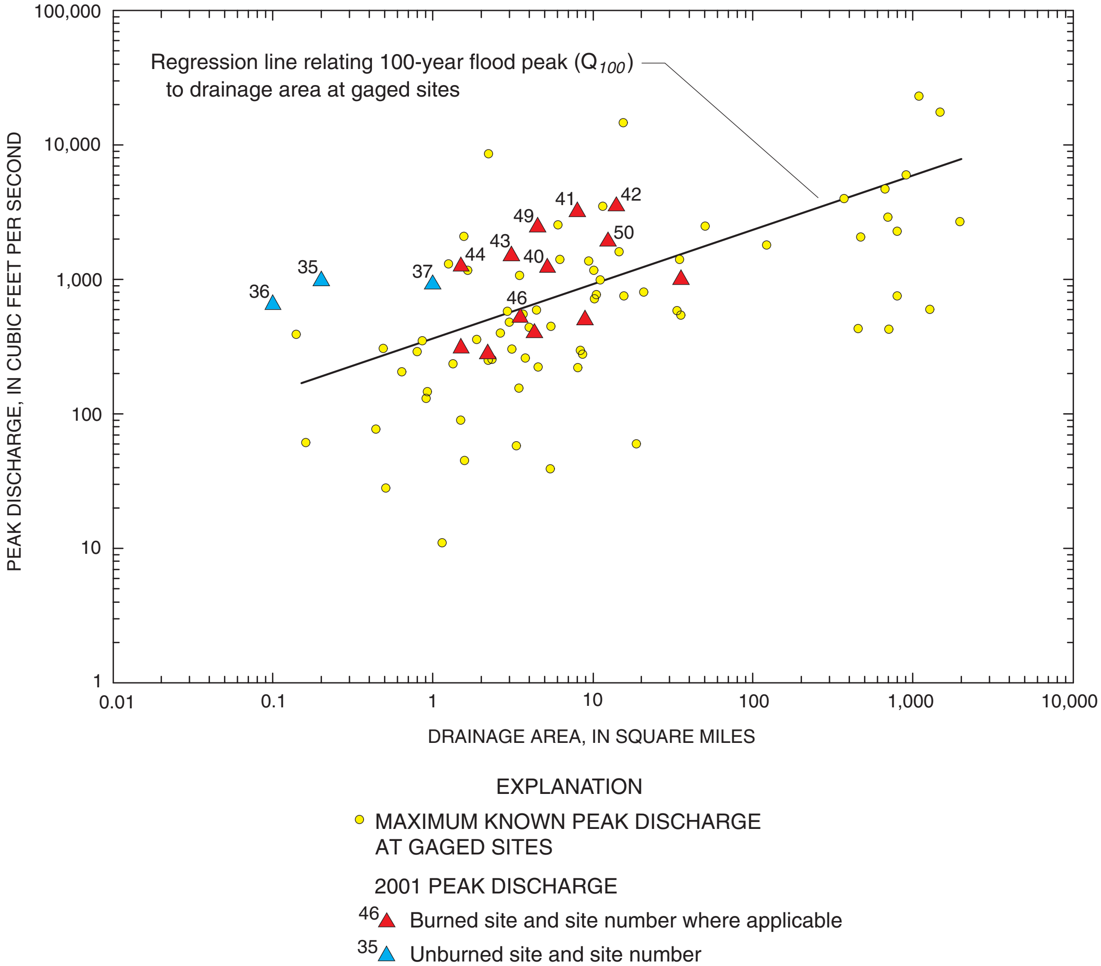


Figure 5. Maximum known peak discharges at gaged sites in the Southeast Plains Region of Montana (Parrett and Johnson, 2004) compared to 2001 peak discharges in the Ashland study area.

the gage recorded 0.53 inch in 15 minutes and 0.76 inch in an hour. On July 20, rain depths were similar at the two Laird Creek sites and at the North Rye Creek site. The 15-minute rain depths at the three sites ranged from 0.31 to 0.39 inch, and the hourly rain depths ranged from 0.41 to 0.43 inch. Rain depths on July 21 were similar to those on July 20 at the two Laird Creek sites and similar to those on July 21 at the Sleeping Child Creek site.

As shown in table 2, the recurrence intervals for the rain depths ranged from less than 2 years for the daily total at all sites for all storms to 25 years for the 15-minute duration for the July 15 storm at Sleeping Child Creek (site 14). Each site had at least one short-duration (5-, 10-, 15-, or 30-minute) depth for at least one storm with a recurrence interval of 10-25 years.

In the Bitterroot study area, the July storms first caused flooding in the heavily burned North Rye Creek basin (site 6, drainage area of 17.5 square miles). Although the flooding deposited debris on hay fields near the mouth and caused substantial channel erosion, it did little or no structural damage. The peak flood discharge for the July 15 storm was calculated to be 260 cubic feet per second at site 6 (table 3, fig. 1). The estimated recurrence interval for this discharge was 100 years. On July 20, flooding occurred in the heavily burned Laird Creek basin (site 2, drainage area of 9.3 square miles). Flood deposits from several Laird Creek tributaries spilled onto the narrow valley floor and partly diverted the main Laird Creek channel (fig. 6). Debris and floodwaters from Laird Creek damaged several homes that had previously suffered fire damage in

Figure 6. Flood deposits from Laird Creek tributary partly blocked the Laird Creek channel (upstream from site 2) following storms of July 20 and 21, 2001, near Sula, Montana.

2000. Floodwaters overtopped Highway 93 and backed up along the highway to flood commercial buildings several hundred feet south of the main Laird Creek channel. On the following day, a similar storm caused more damaging floods. Homes and structures in the narrow valley were again damaged by mud, debris, and floodwaters; Highway 93 was again overtopped. The peak discharges at site 2 on July 20 and July 21 were similar—210 and 220 cubic feet per second (table 3). The recurrence intervals for these peak discharges were 200-500 years. Hydrographs for the July 20 and 21 floods for the gage at site 2 are shown in figure 7 along with a line showing the 200-year flood discharge of 200 cubic feet per second. The calculated peak discharge at site 4 on Laird Creek above Gilbert Creek (table 3), where the drainage basin size is 5.1 square miles, was 160 cubic feet per second. Although only one set of high-water marks was found at this upper site, the peak discharges for July 20 and 21 were presumed to be about the same magnitude, based on the data for the lower site. The recurrence interval for a peak discharge of 160 cubic feet per second at the upper site on Laird Creek was 200-500 years.

Debris-Flow Data and Analysis

Sleeping Child Creek had only minor flooding from the storm of July 15 but several tributaries to Sleeping Child Creek, mostly draining from the north side, produced debris flows that deposited thousands of cubic yards of mostly rock debris on the narrow Sleeping Child Creek valley floor. In several places, the debris-flow deposits completely blocked the main Sleeping Child Creek channel and forced the stream to cut a new channel along the south side of the V-shaped valley. The large volumes of debris deposited at the mouths of the tributary streams originated in the steep tributary channels upstream from the areas of deposition. These tributary channels all exhibited deep, vertical erosion of as much as 15 feet in some reaches.

Peak debris-flow discharge was estimated at several of the tributary channels (sites 51-55, 57; table 4;

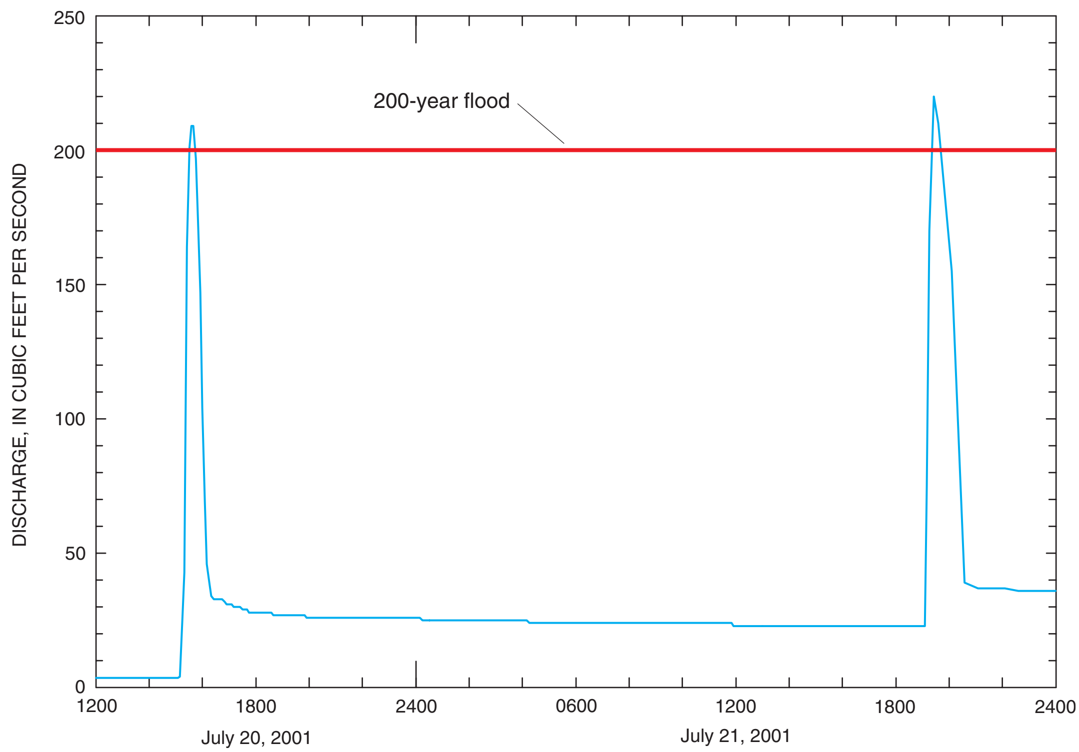


Figure 7. Hydrographs of floods for Laird Creek near Sula, Montana (site 2), July 20 and 21, 2001.

fig. 1) where the erosion and subsequent deposition was especially large (fig. 8). Calculated peak debris-flow discharges ranged from 1,740 to 7,860 cubic feet per second for drainage areas ranging from 0.07 to 0.41 square mile. At one of the largest tributary sites (site 56), flow deposits did not form levees, were generally sorted by size, and did not have any evident fine-grained matrix support. Consequently, the peak discharge at this site was considered to be a hyper-concentrated flow rather than a debris flow (Costa and Jarrett, 1981) and was estimated as a water discharge (table 3).

Debris-flow discharge was calculated at channel sites where the downstream gradient suddenly steepened and where a transition from subcritical flow to critical flow was considered possible. At such flow transitions, the discharge is more dependent upon gravitational acceleration than frictional resistance and can be calculated from the following equation (Henderson, 1966):

$$Q = \left(\frac{gA^3}{B}\right)^{0.5} \qquad (1)$$

where

Q is the peak debris-flow discharge, in cubic feet per second,

g is the gravitational acceleration constant, 32.2 feet per second squared,

A is the cross-sectional flow area, in square feet, and

B is the top width of the flow cross section, in feet.

A single channel cross section encompassing the tops of the debris-flow deposits or scour marks on each side of the channel was surveyed at a location assumed to best represent the break in channel gradient, and equation 1 was used to calculate peak debris-flow discharge. In very steep mountain channels, debris flows may be predominantly supercritical rather than subcritical, and application of equation 1 may yield calculated

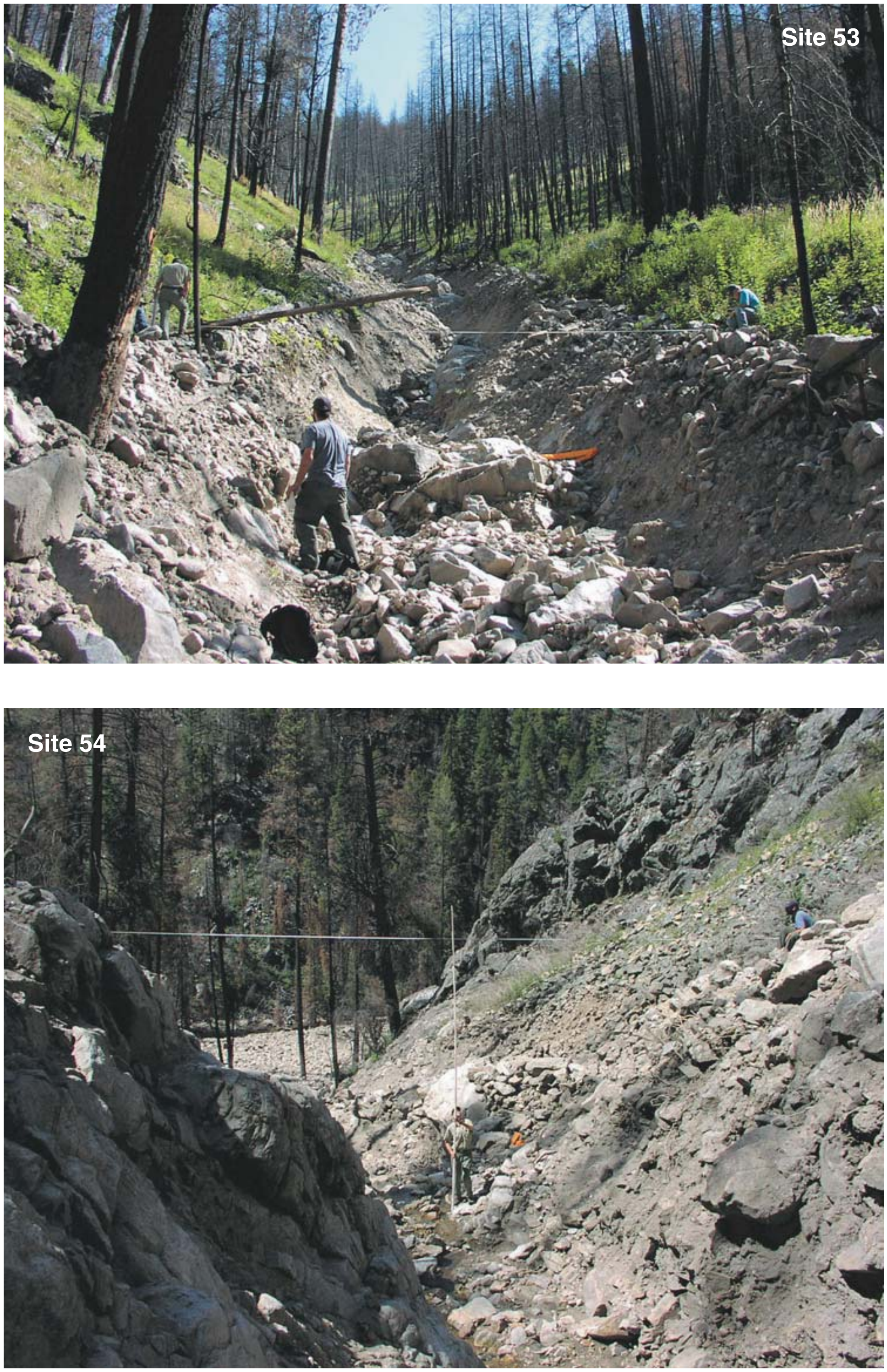


Figure 8. Measuring debris-flow channel section at two unnamed tributaries to Sleeping Child Creek (sites 53 and 54), Montana.

peak debris-flow discharges that are smaller than actual discharges.

Because of some uncertainty about the applicability of the critical-flow equation to Bingham fluids like debris flows and uncertainty about the transition from an assumed subcritical flow condition to a critical flow condition in steep channels, the peak debris-flow discharges calculated for this report are shown as estimates. Debris-flow discharge also is not directly comparable to flood discharge because debris flows are comprised of a high percentage of solids by volume, whereas floods are composed mostly of water. Thus, debris-flow discharge from a given size drainage may be much larger than even a very rare flood discharge. Table 4 presents data for the peak debris-flow discharges estimated for sites in the Sleeping Child drainage, along with drainage areas and average main-channel slopes estimated from USGS 7.5-minute quadrangle maps. Main-channel slope was determined by subtracting the elevation at the channel mouth from that at the drainage divide and dividing the result by the length of channel from the mouth to the divide. The calculated main-channel slopes represent the overall channel steepness in the small basins where debris flows occurred, and not necessarily the steepness of the channel at the sites where peak debris-flow discharges were estimated. As shown on table 4, the main-channel slopes for all the debris-discharge sites were greater than 0.15 foot per foot.

Although the peak debris-flow discharges were spectacularly large in comparison to flood discharges anywhere in the Bitterroot study area, the debris-flow discharges had only a small effect on streamflow in Sleeping Child Creek. The peak flood discharge at site 13 on Sleeping Child Creek resulting from the July 15 storm was only about 150 cubic feet per second. The recurrence interval for a peak discharge of this magnitude is less than 2 years. The crest-stage gage indicated several smaller peak flood discharges also occurred after the peak of 150 cubic feet per second. These smaller peaks may have been the result of short-lived channel blockages from tributary debris flows that sub-

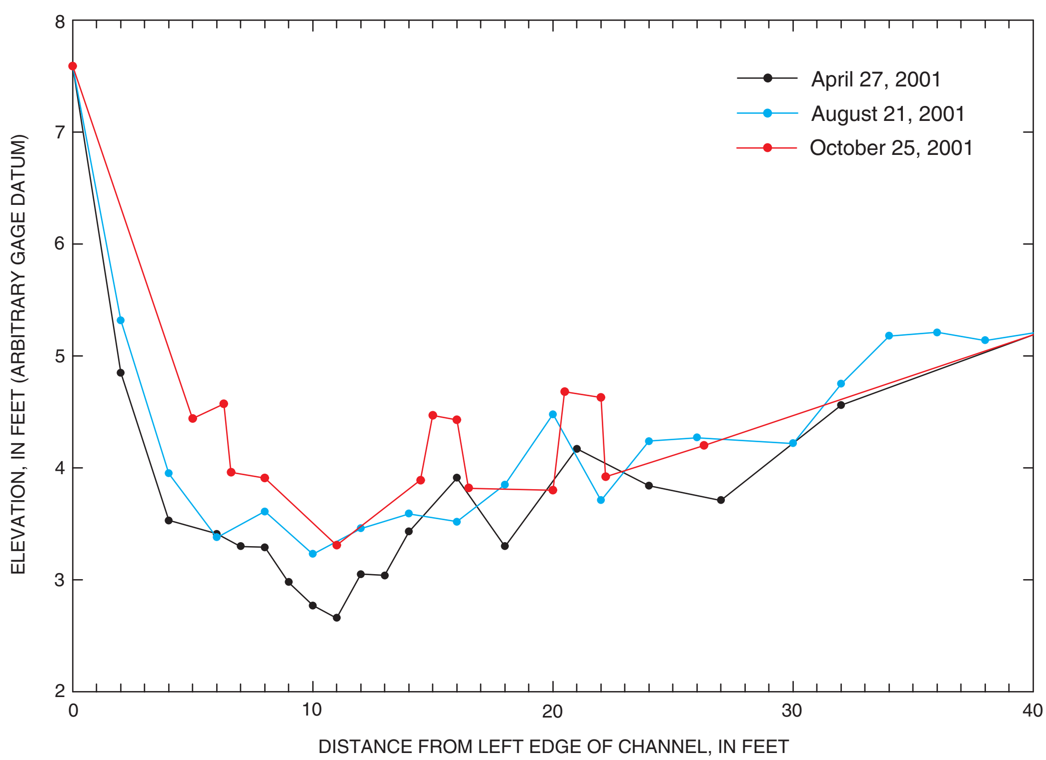


Figure 9. Comparison of surveyed channel cross sections at Sleeping Child Creek near Hamilton, Montana (site 13), before and after debris flows of July 15, 2001.

sequently eroded from the channel. The upstream channel blockages contributed additional sand-sized sediment to Sleeping Child Creek. Figure 9 shows the channel section at site 13 in April 2001 (before the July debris flows), compared to the channel section surveyed in August and again in October 2001. The comparison indicates that the channel aggraded about 0.3 foot from April to August and another 0.2 foot from August to October. Further aggradation may take place as sediment from upstream debris-flow deposits moves downstream, but cyclic variations in runoff also may result in cyclic changes from aggradation to degradation. Overall, given the size of the upstream debris-flow discharges and the several main-channel blockages, the debris flows had a notably small effect on streamflow in Sleeping Child Creek downstream at site 13. Following the large debris flows in July, a continuous-recording streamflow gage was placed at the Sleeping Child Creek gage site (site 13).

Debris-flow process in the Sleeping Child Creek basin

The debris flows on the small steep tributaries of Sleeping Child Creek appeared to have originated about one-third of the distance down from the drainage divides to the tributary mouths. Soil-slips, a type of landslide that commonly mobilizes into debris flows, were not evident. Rather, the debris flows started as a result of bulking of overland runoff with material eroded from the hillslopes and channels. Field observations indicated that overland runoff high on the hillslopes coalesced into numerous small rills. The rills then converged in the shallow swales that serve as channels in the upper parts of the small basins. The runoff, once concentrated, began eroding the channel bed as a series of stepped plunge pools. The uppermost plunge pools were just a few square inches in area and a few inches deep, but with progression down the swales, the pools increased in area and depth. The plunge pools often eroded into unconsolidated material laced by a mesh of fine roots. In many cases, the pools were observed to form immediately below large roots or rocks in the flow path. Less frequently, plunge pools formed immediately below locations where the flowing material dammed, and then breeched. Localized deposits of material were observed immediately downslope from some of the plunge pools or along the flow path behind obstructions such as trees or rocks. In the upper parts of the basins, the deposits primarily consisted of well-sorted sands and silts. With progression downstream, the sorting of the deposits decreased, and the size of the materials and amount of matrix increased. At a distance about one-third of the total channel length, the deposits, although discontinuous, were characterized by poor sorting, random orientation of the clasts, and fine-grained matrix support of the larger clasts. These features, which are commonly associated with fire-related debris-flow activity (Meyer and Wells, 1997; Cannon and others, 2001), indicate that sufficient material had been entrained, relative to the amount of runoff, to impart debris-flow characteristics to the flow. At a distance about midway between the drainage divides and channel mouths, the deposits formed continuous levees lining the channel. In addition, depths of channel erosion increased, and the series of discrete plunge pools were replaced by continuous channel incision, leaving steep, nearly vertical banks. At the narrow valley floor of Sleeping Child Creek, the channels were incised as much as 15 feet. The deep channel incisions revealed that the channels were filled with thick accumulations of colluvium prior to the debris-flow events of July 2001 and that virtually all sediment composing the debris flows originated in the channels. A similar process of progressive channel erosion in burned areas resulting in debris flows was found in New Mexico (Cannon and others, 2003) and in Colorado (Cannon and others, 2001), although in the Colorado case the major source of eroded material in that area was the hillslope and not the channel.

IMPLICATIONS FOR FUTURE FLOODS AND DEBRIS FLOWS

Storm intensity and the resultant degree of flooding and debris flows that occurred in 2001 varied widely among the three study areas. Although data are few, the largest and rarest storms were those only 10 days apart in the Ashland study area. These storms also resulted in the largest floods, with many calculated peak discharges greatly exceeding those with 500-year recurrence intervals for unburned conditions. Ironically, however, any correlation between wildfire and flooding is hard to discern in the Ashland study area, because the storms were so large and rare. Indeed, based on a plot of peak discharge and drainage area, calculated flood peaks for three unburned drainages were just as large as or larger than any of the calculated peak discharges for streams draining burned areas. In addition, debris flows, which are relatively common in many burned areas shortly after fires and which were evident in both the Canyon

Ferry and Bitterroot study areas, were notably absent in the Ashland study area. On this basis, wildfire may not have been a major factor in the degree of flooding that occurred in the Ashland study area.

In the Canyon Ferry and Bitterroot study areas, several factors were common in 2001. First, flooding or debris flows generally occurred only when storm depths for the shorter (5-, 10-, and 15-minute) durations were greater than about 0.2-0.3 inch. Second, floods occurred more than once on several streams and the degree of flooding from the second storm generally was as great as or greater than that from the first storm. This second finding indicates that thunderstorm-caused flood peaks as large as those in 2001 might be a common annual occurrence on some streams until permanent vegetation is re-established. Third, significant debris-flow activity occurred only in burned drainages smaller than 1 square mile with channel gradients steeper than about 20 percent. Thus, numerous small, steep drainages in burned areas currently (2003) without significant debris flows are probably still highly susceptible to this process until permanent vegetation is re-established.

SUMMARY

In summer 2000 more than 900,000 acres were burned by wildfire in Montana. On September 30-October 1, 2000, a large frontal storm moved generally northeast through the largest burned area in the Bitterroot River drainage basin and caused minor debris flows at several sites and a flood having a recurrence interval of about 100 years, based on unburned conditions, on Little Sleeping Child Creek. The sparse rainfall data indicated that, while 24-hour precipitation depths were significant in 2000, short-duration rainfall amounts evidently were small. The U.S. Geological Survey, in cooperation with the Montana Department of Transportation and the Bitterroot National Forest, installed a streamflow-gaging station, several crest-stage gages, and several tipping-bucket rain gages in anticipation of additional flooding and debris flows in 2001.

Beginning in late May 2001, a series of convective thunderstorms across Montana caused significant runoff and debris flows in three burned areas. The first area affected was the Canyon Ferry area near Helena, where debris flows blocked a road, and flooding from Cave Gulch and Crittenden Gulch caused structural damage. Rainfall data from early storms were sparse, but short-duration rainfall amounts evidently were significant. Several tipping-bucket rain gages were installed in the Canyon Ferry area following the May storms. Storms in the Canyon Ferry area in mid-July again caused flooding from Crittenden Gulch, Magpie Creek, and Hellgate Gulch. Short-duration rainfall amounts had recurrence intervals of as much as 5-10 years, while flood peaks had recurrence intervals up to 200 years, based on unburned conditions.

Large thunderstorms in late June and early July 2001 moved through the Ashland study area and caused substantial flooding from tributaries to Otter Creek and the Tongue River. Based on data at one USGS gage, rainfall depth for the 5-minute duration had a recurrence interval of 100-500 years. Based on unofficial reports, rainfall depths for the 30-minute duration for the June 30 storm and for the 2-hour duration for the July 10 storm both had recurrence intervals greater than 500 years. Calculated flood peaks had recurrence intervals equal to or greater than 50 years at 16 sites and greater than 500 years at 10 sites. At most of the flood sites in the Ashland area, the streams drained burned areas. However, at three sites (35, 36, and 37) where the calculated flood peaks had greater than 500-year recurrence intervals, the streams drained unburned areas. The fires in 2000 may have had less effect on the large floods in the Ashland area in 2001 than did the severity of the storms.

A series of thunderstorms on July 15, 20, and 21 caused flooding and large debris flows in the Bitterroot study area. Rainfall depths for the storm of July 15 had recurrence intervals of 10-25 years for 10- and 15-minute durations at one USGS gage and recurrence intervals of 10-25 years for 10- and 30-minute durations at another. The calculated peak discharge on North Fork Rye Creek from the July 15 storm had a recurrence interval of 100 years, based on unburned conditions. The storms on July 20 and 21 resulted in flooding on Laird Creek. The rain depths at two USGS gages in the Laird Creek drainage had maximum recurrence intervals of 10-25 years for durations of 5-, 10-, and 15-minutes. The two successive storms resulted in almost identical flood peaks on Laird Creek. The recurrence interval for the peaks was 200-500 years, based on unburned conditions.

Significant debris-flow activity on small, steep tributary streams to Sleeping Child Creek resulted from

the storm of July 15. The main channel of Sleeping Child Creek was diverted and temporarily blocked by several of the tributary debris flows. Peak debris-flow discharges were calculated at several tributary sites. The maximum calculated debris-flow discharge was 7,860 cubic feet per second from a tributary draining only 0.28 square mile of severely burned forest. The debris flows were associated with steep channel slopes on severely burned areas. The debris flows, which originated about one-third of the distance down from the drainage divides to the tributary mouths, were caused by overland runoff that coalesced into rills and swales and progressively eroded the channels from a condition of widely spaced stepped plunge pools to a condition of continuous channel incision.

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