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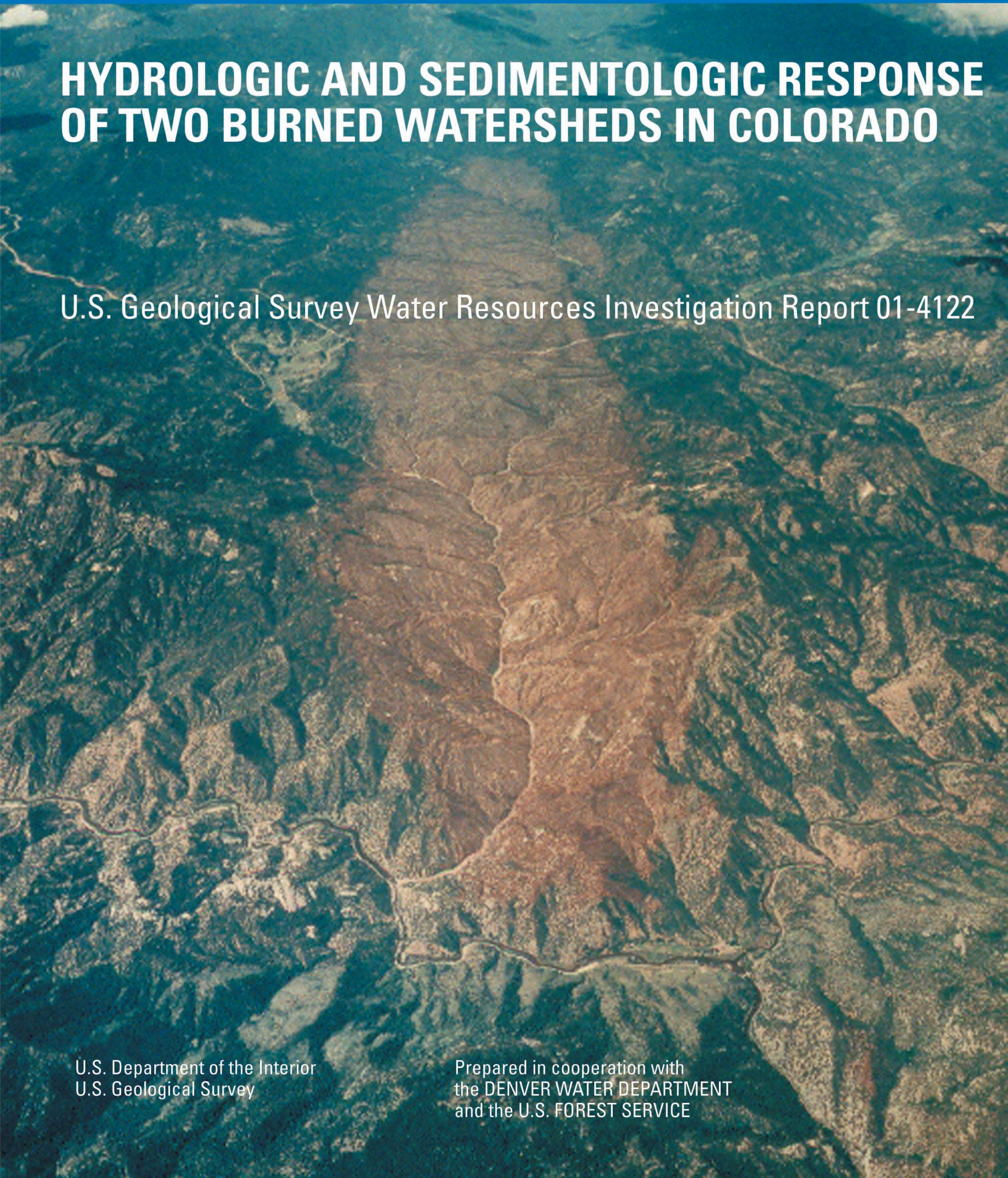

HYDROLOGIC AND SEDIMENTOLOGIC RESPONSE OF TWO BURNED WATERSHEDS IN COLORADO

U.S. Geological Survey Water Resources Investigation Report 01-4122

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

Prepared in cooperation with
the DENVER WATER DEPARTMENT
and the U.S. FOREST SERVICE

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by John A. Moody and Deborah A. Martin

U.S. Geological Survey

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Denver, Colorado
2001

U. S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY

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Cover Photo: Courtesy of Pat Lang and unknown photographer, Buffalo Creek, Colorado. Aerial view of the Buffalo Creek burned area looking west with Spring Creek in the foreground draining into the South Platte River.

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CONVERSION FACTORS AND DEFINITION OF SYMBOLS

Multiply	***By***	***To obtain***
meter (m)	3.281	foot (ft)
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	2.471	acres
cubic meter (m^3)	1.308	cubic yard (yd^3)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic feet per second (ft^3/s)
gram (g	0.03527	ounce avoirdupois (oz)
kilogram (kg)	2.205	pounds (lb)
newton (N)	7.235	slug (slug)

SYMBOLS

A = cross-sectional area (m^2)
A_c = contributing area (m^2)
B = local channel slope
d = east offset for coordinate transformation (m)
E = UTM east coordinate (m)
E' = arbitrary east coordinate (m)
e = north offset for coordinate transformation (m)
D* = diameter of a particle with fall velocity equal to the shear velocity (mm)
D_{50} = diameter for which 50 percent of particles are smaller, the median diamater
D_{16} = diameter for which 16 percent of particles are smaller
D_{84} = diameter for which 84 percent of particles are smaller
D_b = median diameter of largest size-class transported as bedload (mm)
D_s = diameter of largest particle moving as suspended load (mm)
f = scale factor
g = acceleration of gravity (m/s^2)
h = mean depth (m)
I_{30} = maximum 30-minute rainfall intensity (mm/h)
L = cumulative stream-length (m)
N = UTM north coordinate (m)
N' = arbitrary east coordinate (m)
n = number of linear reservoirs
K = empirical constant in linear reservoir model (minutes)

Q = discharge (m^3/s)
R = hydraulic radius (m)
S = water surface slope
Sc = Cory shape factor
u* = shear velocity (m/s)
w = channel top width (m)
w_z = fall or settling velocity (m/s)
Z = elevation above sea level (m)
Z' =arbitrary elevation above sea level (m)
z = elevation offset for coordinate transformation (m)
θ = rotation angle (degees)
α = minor axis of sediment particle (mm)
β = minor axis of sediment particle (mm)
γ = major axis of sediment particle (mm)
υ = kinematic viscosity of water (m^2/s)
ρs = density of sediment (kg/m^3)
ρ = density of water (kg/m^3)
σ = sorting or dispersion coefficient
ϕ_1 = slope of the side of the channel perpendicular to axis
ϕ_2 =slope of the side of the channel perpendicular to axis
τ = shear stress ($N\ m^{-2}$)
τ^* = non-dimensional shear stress
τ^*_c = non-dimensional shear stress required to initiate motion

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ABSTRACT

A wildfire in May 1996 burned two mountain watersheds southwest of Denver, Colorado. In June and July 1996, intense rain from several thunderstorms caused erosion of sediment from hill-slopes and channels in these two watersheds, resulting in deposition of sediment in Strontia Springs Reservoir, a major water-supply reservoir for the cities of Denver and Aurora. A study was begun in 1997 to measure the hydrologic and sedimentologic responses of these burned watersheds to subsequent rainstorms.

The rainfall characteristics after the wildfire indicate that 1997 was an above average year for rainfall. The rainfall-runoff relation indicates that a threshold of rainfall intensity exists, above which severe flash floods occur. The sediment-erosion rates on the hillslope decreased from a maximum of at least 0.048 kg/m/d (kilograms per meter per day) in 1997 to an average of 0.00054 kg/m/d in 2000 which approached the pre-fire rate. Sediment transport from the water-sheds after the wildfire was 5-10 times greater than before the wildfire but also decreased during the four years of the post-fire study. Sediment from the initial erosion in 1996 is still stored in the channels of the watersheds. Near the mouth of one watershed there has been a net aggradation of the bed while near the mouth of the other watershed the channel has been scoured back down to the pre-fire level. Initial deposition in the Strontia Springs Reservoir was 52,000 m^3 (cubic meters) of coarse sand and gravel, which created a delta in the upper end of the reservoir, and 100,000 m^3 of silt and clay near the dam. Subsequent deposition in the reservoir has added about 200,000 m^3 of coarse sand and gravel and an unmeasured amount of silt and clay.

Recovery of these burned watersheds within about five years seems typical as documented in the scientific literature; however, the reader should be cautious about assuming that runoff and erosion will continue to decrease. The runoff and erosion response was only monitored for four years after the Buffalo Creek Fire and the rainfall has been normal or below normal since 1997.

Section 1--INTRODUCTION

In May 1996, the Buffalo Creek Fire burned approximately 50 km^2 in the Pike National Forest southwest of Denver, Colorado. The fire burned two adjacent sixth-level watersheds (U.S. Forest Service, 1995), Buffalo Creek and Spring Creek (fig. 1.1). A larger proportion of the Spring Creek watershed burned, 79 percent, compared with the Buffalo Creek watershed, 21 percent (table 1.1). Bruggink and others (1998), characterized the majority of the burned area as severely burned (63 percent), based on the consumption of litter and duff and the visible effects of the fire on the needles and branches of conifers, the predominant woody vegetation. Two months after the fire, an intense rainstorm (110 mm in an hour; Jarrett, 2001) caused severe flooding, erosion, and the death of two people. The flood transported large quantities of sediment and organic debris to Strontia Springs Reservoir on the South Platte River, a major water-supply reservoir for the cities of Denver and Aurora. The Denver Water Department and the U.S. Forest Service provided funding to assess the potential impact of sediment erosion in the burned watersheds and on the downstream water-supply systems.

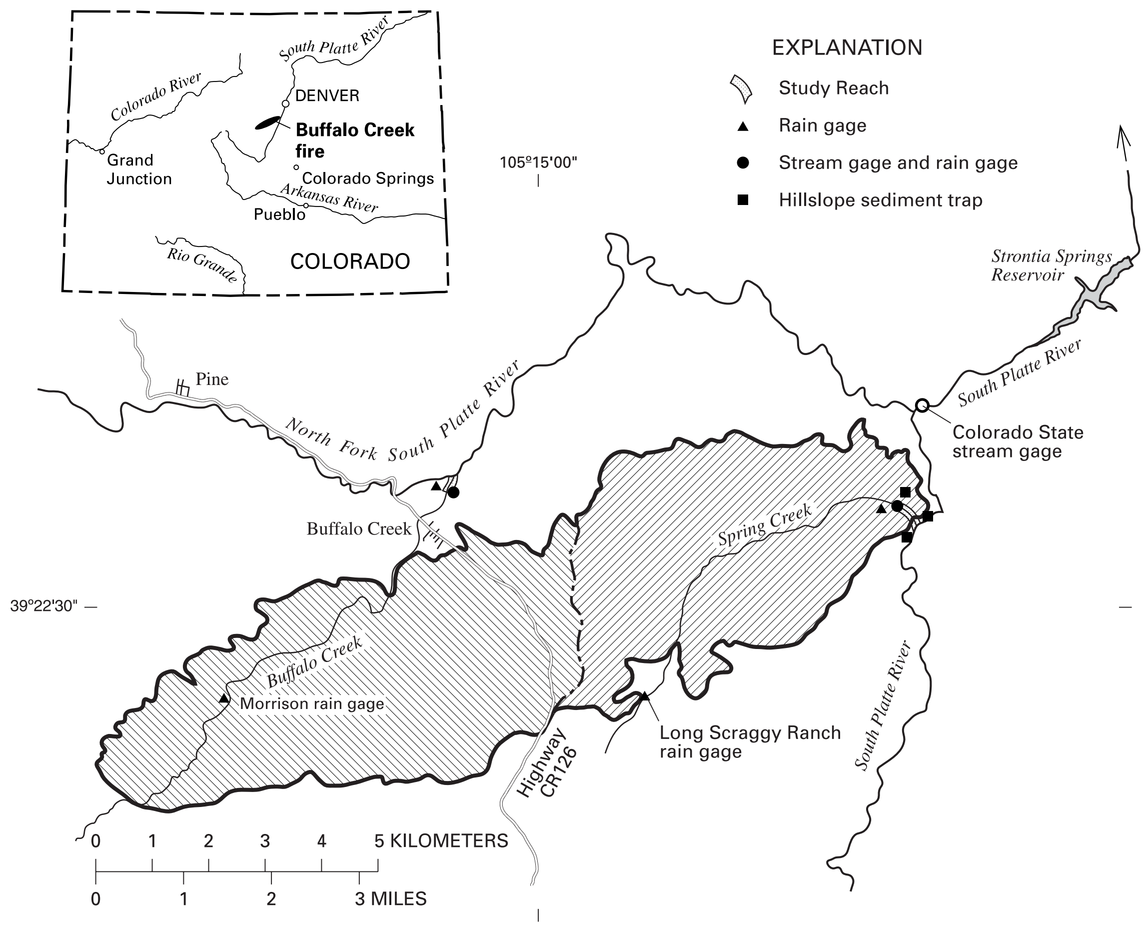

Figure 1.1 Location of the study sites within the two burned watersheds.

Objectives and Scope

Following the fire, the U.S. Geological Survey (USGS) initiated several studies in the two burned watersheds. The objectives of these studies were: (1) to use rainfall and stream gage data to develop a rainfall-runoff relation for burned watersheds; (2) to measure the hydrological and erosional responses of severely burned hillslopes by monitoring hillslope runoff, erosion in rills, and erosion from inter-rill areas; (3) to measure erosion and deposition in first to fourth order drainages; (4) to measure the volume of post-fire sediment deposited in the channels and monitor the flux of sediment from the watersheds; (5) to develop sediment rating curves for the two burned watersheds and compare these curves with pre-fire curves; and (6) to monitor the flux of sediment into Strontia Springs Reservoir. These studies began in 1996 and are planned to monitor the recovery of the burned watersheds over a long period of time. This report presents results from studies conducted from 1996 through 2000. Most efforts have been in the Spring Creek watershed because more extensive post-fire rehabilitation was carried out in the Buffalo Creek watershed, and an overall objective is to understand the “natural” response to and recovery from wildfire.

Watershed Characteristics

Buffalo and Spring Creek watersheds are located in the Front Range of the Rocky Mountains, underlain by the Pikes Peak batholith. They cover an elevation range of 1,880 to 3,180 m (table 1.1). Soils belong to the Sphinx-Legault-Rock outcrop complex (Moore, 1992). Depths to bedrock are quite variable, and the soil profile includes emerging corestones and thick layers of

Table 1.1. Characteristics of Buffalo and Spring Creeks watersheds

[ha, hectare; m, meter; km, kilometer; m^3/s, cubic meter per second]

Characteristics	Buffalo Creek	Spring Creek
Watershed level	6	6
Watershed area (ha)	12,240	2,680
Burned area (ha)	2,570	2,120
Elevation range (m)	2,010-3,180	1,880-2,360
Relief ratio in the burned area	0.020	0.046
Main channel length in burned area (km)	7.3	5.9
Channel lengths in burned area (km)	180[a]	150
Bifurcation ratio	3.9[b]	4.1
Average valley width near mouth (m)	35	27
Range in channel width near mouth (m)	3-13	1-26
Main channel slope (%)	1-2	3-4
Channel density (1/km)	7.1[b]	6.9
Distance of mouth from Strontia Springs Reservoir (km)	18	4.8
Baseflow: June, July, August 1997-98 (m^3/s)	0.7	0.07

[a]Channel length is equal to channel density times the burned area.

[b]This value is the average of three subwatersheds.

decomposed granite called grüs, similar to the conditions described by Isherwood and Street (1976) for the Boulder, Colorado, batholith. In general, however, the soils of the Sphinx-Legault-Rock outcrop complex are shallow (about 0.4 m to the weathered bedrock), well to excessively drained, and low in organic matter (2 percent or less). Material mantling the hillslope is generally coarse (about 7 percent silt and clay, 35 percent sand, 58 percent gravel) with a median diameter of 2.6 to 2.9 mm (Martin and Moody, 2001). Soils are classified as Typic Ustorthents on south-facing hillslopes and as Typic Cryorthents on north-facing hillslopes (Blair, 1976; Moore, 1992; Welter, 1995). These soils have a typical erodibility factor, K (Renard and others, 1997), of 0.49 m^{-1}, a high runoff potential when thoroughly wet (primarily because of the very shallow depth to bedrock), and are considered to be highly erodible if the soil cover is disturbed (Moore, 1992).

The vegetation growing on these soils is montane forest with ponderosa pine (*Pinus ponderosa*) and some Rocky Mountain juniper (*Juniperus scopulorum*) occurring mainly on south- and west-facing slopes, and Douglas-fir (*Pseudotsuga menziesii*) on the north- and east-facing slopes, though a mix of all tree species can occur on any aspect. The litter and duff layer, consisting mainly of undecomposed to partially decomposed conifer needles, is thick (75-100 mm; Jarrett, 2001) and fairly extensive, especially on the north- and east-facing aspects. Like much of the Colorado Front Range, both extensive grazing and active fire suppression for over 100 years have allowed tree densities to increase above the densities typical of the pre-fire suppression era (Brown and others, 1999; Kaufmann and others, 2000a, 2000b). Very little understory vegetation exists on unburned north-facing slopes because of competition for light and nutrients under the closed Douglas fir canopy. However, after the fire the north-facing, burned hillslopes have developed a dense cover of herbaceous vegetation (including creeping dogbane, *Apocynum androsaemifolium*, sugarbowl, *Clematis hirsutissima*, and leafy spurge, *Euphorbia esula*). On south- and west-facing aspects, the litter and duff layer occurs mainly under ponderosa pines, bunch grasses (Arizona fescue, *Festuca arizonica*, and others; Moore, 1992), and shrubs (Gambel oak, *Quercus gambeli*). Bare ground is common on the hillslopes between trees, grasses, and shrubs. Except for ponderosa pine and Rocky Mountain juniper, this assemblage of vegetation has recovered to almost pre-fire conditions on burned south-facing slopes. Before the fire, the riparian vegetation in Spring Creek consisted of stands of willow (*Salix ssp.*) and narrowleaf cottonwood (*Populus angustifolia*) (Moore, 1992; U.S. Forest Service, 1996). Along Spring Creek, after the fire, most of the riparian vegetation was either buried by sediment or scoured out by the post-fire flooding, while along Buffalo Creek, the riparian zone had more coniferous trees and was less scoured by the post-fire flooding.

Land Use History

The two watersheds have a well-documented land-use history since the turn of the century. This history indicates that erosion has occurred in this area as a result of fire and human activities. In 1899 both the Buffalo Creek and Spring Creek watersheds were part of the South Platte Forest Reserve administered by the USGS (Jack, 1900). The Forest Reserves had been set aside to protect land and water supplies for the Nation under the Forest Reserve Act of 1891 (Steen, 1991). After the creation of the U.S. Forest Service in 1905, the study area became part of the Pike National Forest in 1907. Jack (1900) describes the extent of area burned within the adjacent South Platte, Plum and Pikes Peak Forest Reserves: "Probably at least 75 percent of the total area of the reserves clearly shows damage by fire, much of it within the last half century or since the advent of white settlers in the region; and a great deal of ground shows traces of fires, which must have occurred prior to that time, and the forest has partially recovered the areas then burned over." The area is also described as having “excessive pasturage, by which the ground becomes trampled hard and the protecting vegetation along streams destroyed” (Jack, 1900, p. 43). A 1938 U.S. Forest Service report (Connaughton, 1938) documented significant erosional consequences of overgrazing in the Spring Creek watershed and recommended reducing the number of livestock

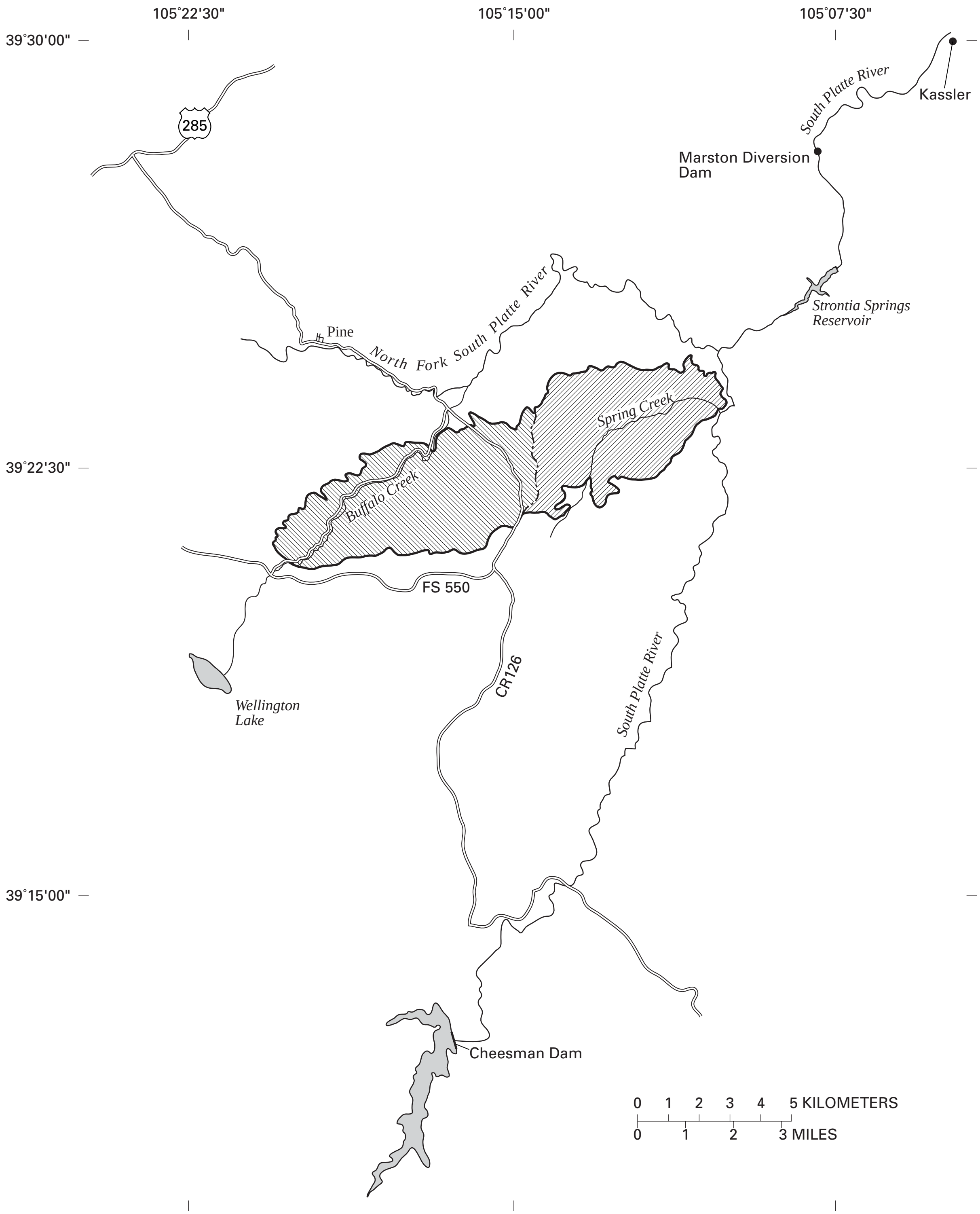

Figure 1.2 Location of long-term regional precipitation stations.

allowed to graze the land. Ample evidence, including reports and archival photography, indicates that this area is highly susceptible to erosion as a result of both fire and overgrazing. Stratigraphic evidence suggests that fire followed by significant erosion may be a process active for at least the last two thousand years (Elliott, 1999; Gonzales and Hunt, 1999; Elliott and Parker, 2001).

Climate, Precipitation Regime, and Hydrology

The climate is semi-arid, and precipitation is dominated by intense summer convective storms and winter snow storms. Based on long-term precipitation and temperature means from nearby weather stations at Cheesman, Kassler and Strontia Springs Dam (fig. 1.2), about one-third to one-half of the precipitation occurs during the summer months of June through September (table 1.2). According to Jarrett (1990) flooding in this area mainly results from intense, localized thunderstorms, but can also result from generalized rainstorms and spring snowmelt. Rainfall

Table 1.2. Long-term precipitation and temperature records from Cheesman, Kassler, and Strontia Springs Dam, Colorado

[Source: Colorado Climate Center, 2001; m, meter; mm, millimeter; ^{o}C, degree Celsius]

Characteristics	Cheesman	Kassler	Strontia Springs Dam
National Weather Service station ID	51528	54452	58022
Latitude	39^{o}13'	39^{o}30'	39^{o}26'
Longitude	105^{o}17'	105^{o}06'	105^{o}07'
Elevation (m)	2,100	1,676	1,780
Period of record	1950-1997	1950-1997	1984-1997
Mean annual precipitation (mm)	420	442	566
Total summer (June through September) precipitation (mm)	205.7	161.3	229.4
Average number of summer days with precipitation ≥ 2.54 mm	21.3	15.8	22.8
Average number of summer days with precipitation ≥ 25.4 mm	0.9	1.0	1.2
Mean annual maximum temperature (^{o}C)	17	19	17
Mean annual minimum temperature (^{o}C)	-3	2	-1

intensities during these storms range from about 30 mm/h for the 2-year recurrence storm to about 60 mm/h for the 100-year recurrence storm (Miller and others, 1973)

Before the wildfire, Spring Creek had ephemeral and intermittent reaches (Casey Clapsaddle, U.S. Forest Service, oral. commun., 1997) with beaver ponds in certain reaches, as shown in photographs taken soon after the wildfire (D. Bohon, U.S. Forest Service, oral commun., 1997). At present (2001), the stream is still intermittent, disappearing below the sediment in the channel in several reaches. Spring Creek flows into the South Platte River 4.8 km above Strontia Springs

Reservoir (fig. 1.2).

Before the wildfire, Buffalo Creek was a perennial stream with a gravel and cobble bed and little suspended sediment load (Williams and Rosgen, 1989). Water is released each summer for irrigation from Wellington Lake (fig. 1.2) by the Burlington/Wellington Ditch Company. Buffalo Creek flows into the North Fork of the South Platte River 18 km above Strontia Springs Reservoir. The North Fork of the South Platte and the South Platte flow together near the historic town site of South Platte, 1.6 km above Strontia Springs Reservoir. The State of Colorado operates a stream gage (South Platte River at South Platte) just below the confluence.

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Section 2--RAINFALL

Method

In response to the threat of post-fire flooding and erosion, the USGS and the Denver Water Department cooperatively installed four rain gages in or near the area burned by the Buffalo Creek fire. Two rain gages were deployed in the Spring Creek watershed and two in the Buffalo Creek watershed (table 2.1). The locations of the four gages were chosen on the basis of results of Troutman (1982). Prior to the fire, no official rain gages were operated in the vicinity of the burn, though local residents have provided rainfall data (Jarrett, 2001). Other methods, such as radar and paleohydrologic techniques (Henz, 1998; Fulton, 1999; Yates and others, 2000; Jarrett, 2001), have been used to reconstruct the storm that caused the initial post-fire flooding on 12 July 1996.

The rain gages are being used to monitor rainfall in the burned area and to collect rainfall intensities for the development of rainfall-runoff relations for the burned watersheds. The rain gages are either Meteorology Research or Met One tipping-bucket rain gages with 8-inch orifices. The tipping buckets have a 0.01-inch capacity. Sutron 8210 data collection platforms record data at 5-minute intervals. The rain gages have operated on a seasonal basis, April-September of each year, since they were installed (USGS, 1997, 1998, 1999, and 2000). Every 4 hours under normal conditions, the Sutron data collection platforms transmit 15-minute values by a satellite connection. If the rain gage tipping rate exceeds a pre-set threshold, the data are transmitted in random mode, usually on 5-minute intervals for 15 minutes, unless the rain rates continue to exceed the pre-set threshold.

Table 2.1. U. S. Geological Survey rain gages in the Buffalo Creek and Spring Creek watersheds

[These gages are operated from April through September of each year. Current and historic data are available on the Web at http://www.usgs.gov]

	Buffalo Creek at Buffalo Creek, Colorado	Buffalo Creek at Morrison Creek	Spring Creek at Long Scraggy Ranch	Spring Creek above mouth near South Platte, Colorado
U.S. Geological Survey ID	06706800	392133105184401	392144105132401	06701970
Latitude	39°23' 2"	39°21' 3"	39°21' 4"	39°23' 3"
Longitude	105°16' 1"	105°18' 4"	105°13' 2"	105°11' 01"
Elevation (meters)	2,021	2,170	2,219	1,926
Start date	22 June 1997	10 April 1997	24 April 1997	24 April 1997

Rainfall data were used to calculate 30-minute rainfall intensities, storm duration, and total rainfall. To determine rainfall intensity, a moving 30-minute window was applied to an entire rainstorm to identify that part of the storm that had the highest 30-minute intensity, which was expressed in mm/h in order to compare this intensity with values reported in the literature.

Results

The number of rainstorm events, rainfall intensities, and total rainfall have varied throughout the four summers (1997-2000) for the two burned watersheds; in general, these properties seem to have decreased after 1997 (fig. 2.1, table 2.2). Summer is defined as June, July, August and September, a total of 122 days. Because the USGS rain gages were not installed until 1997, no rainfall data exist for the first summer following the wildfire (summer 1996) except for the radar (Henz, 1998; Fulton, 1999; Yates and others, 2000) and paleohydrologic (Jarrett, 2001) reconstructions for the 12 July 1996 storm. The summer of 1997 had more rain, a greater number of storms, and more intense rainfall than the other years of this study. In addition, 1997 appears to have been wetter than long-term averages. For example, at the USGS rain gage (Spring Creek above the

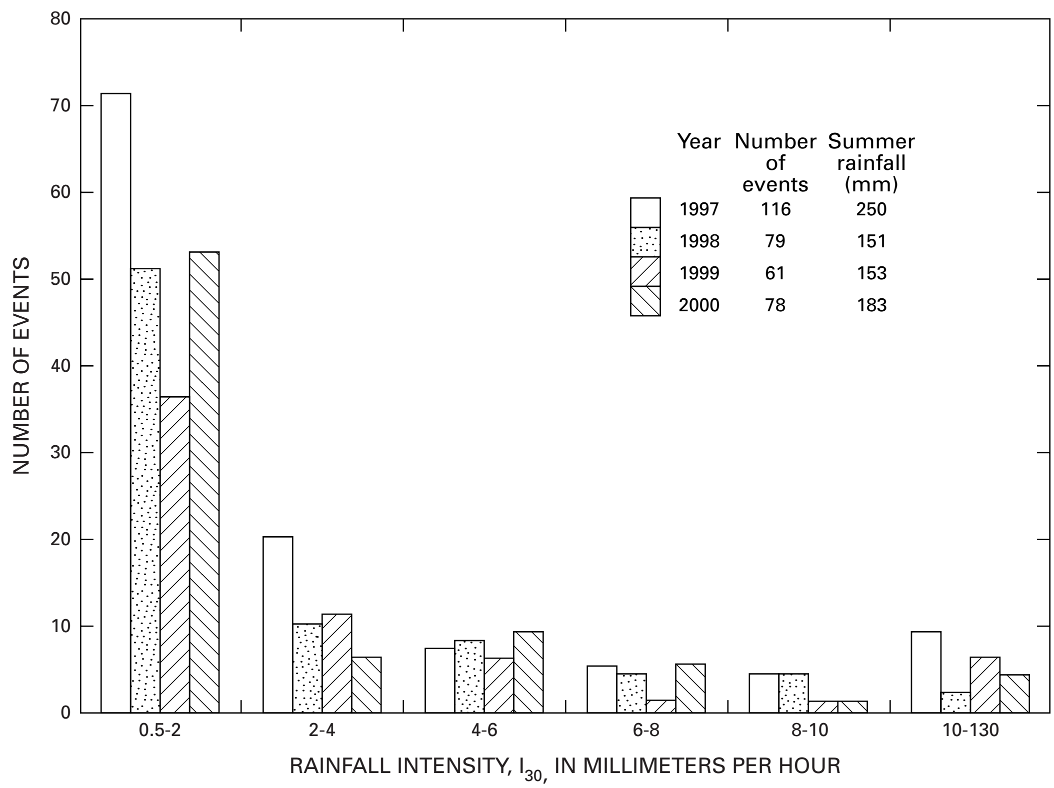


Figure 2.1. Distribution of rainfall intensity (I_{30}) at Spring Creek above mouth near South Platte, Colorado, during the summer (June, July, August, and September).

mouth near South Platte), the total summer rainfall (250 mm) was greater than the long-term averages of 205.7, 161.3 and 229.4 mm for the stations at Cheesman, Kassler, and Strontia Springs Dam, respectively. There were 24 days when the rainfall was greater than or equal to 2.54 mm compared with an average of 20 days for the long-term stations. In general, more rain events occurred in four of the six intensity classes in 1997 than in 1998, 1999, or 2000 (fig. 2.1).

Table 2.2. Rainfall characteristics for four years after the Buffalo Creek Fire

[Rainstorms are separated by more than 15 minutes; mm, millimeter; h, hour; mm/h, millimeter per hour]

	Summer months of June, July, August, and September			
	1997	**1998**	**1999**	**2000**
Total precipitation (mm)--at Morrison Creek	224	123	132	159
Total precipitation (mm)-- at Buffalo Creek	gage was not operating in June	197	159	144
Total precipitation (mm)--at Long Scraggy Ranch	288	270	263	194
Spring Creek above mouth near South Platte, Colorado				
Total precipitation (mm)	250	151	153	185
Number of rainstorms	116	79	61	78
Number of days with precipitation ≥ 2.54 mm	24	20	14	19
Number of days with precipitation ≥ 25.4 mm	1	0	1	1
Mean duration (h)	0.44	0.58	0.70	0.48
Median duration (h)	0.25	0.33	0.50	0.25
Mean I_{30} (mm/h)	3.6	2.5	3.3	3.0
Median I_{30} (mm/h)	1.0	1.0	1.5	1.0
Maximum I_{30} (mm/h)	89	28	35	60
	Number of rainstorm events			
$0.5 < I_{30}$(mm/h) < 2	71	51	36	53
$2 < I_{30}$(mm/h) < 4	20	10	11	6
$4 < I_{30}$(mm/h) < 6	7	8	6	9
$6 < I_{30}$(mm/h) < 8	5	4	1	5
$8 < I_{30}$(mm/h) < 10	4	4	1	1
I_{30}(mm/h) > 10	9	2	6	4

Section 3--RUNOFF

Methods

Stream gages with satellite telemetry were installed near the mouths of Buffalo and Spring Creeks in 1997 (fig. 1.1). Standard bubble gages (Accubar interfaced with Sutron 8210 DCP) were operated on a seasonal basis from about March to November of each year (USGS, 1997, 1998, 1999, and 2000). Stage data were collected every 15 minutes except when a preset stage threshold was exceeded and then data were collected every 5 minutes. The gage on Buffalo Creek was about 600 m upstream from the mouth, and the average slope of the channel below the gage was about 0.01. Channel cross-sections at this gage changed frequently in response to flows from summer rainfall events, which transported sediment into and out of the reach. The gage on Spring Creek was about 1,500 m upstream from the mouth in a narrow (10 m wide) and stable bedrock channel with an average slope of about 0.04. Little sediment was deposited or eroded from this reach, but during some flood events, moving cobbles and boulders damaged the gage orifice and no hydrographs were recorded. Indirect discharge measurements were made after these events in addition to the standard discharge measurements made throughout the gaging season (tables 3.1 and 3.2). Additional discharge measurements were made at the mouth of Spring Creek using a wooden Parshall flume (Grant, 1991). After the flume was destroyed in 1997 by a flood, measurements were made using Price-AA current meters, or surface floats when the water was too shallow for current meters. Surface velocities were converted to depth-averaged velocity by multiplying by 0.86 (Rantz and others, 1982).

Peak discharges following rainfall events were determined from the recorded hydrograph as the maximum value above the discharge preceding the event. Some days had more than one event (table 3.3). The corresponding 30-minute rainfall intensity, I_{30}, was also measured for each event at the two rain gages in the Spring Creek watershed. These two values of I_{30} were averaged and are reported in table 3.3 along with the unit-area peak discharge estimates. Some rainfall events created floods, which were defined as flows with peak discharges greater than 10 times the baseflow for June, July, and August 1997 and 1998 (0.7 and 0.07 m^3/s, table 1.1) or where the average I_{30} was greater than 10 mm/h. The unit-area peak discharge for these post-fire floods was calculated by dividing the peak discharge by the burned area for each watershed (table 1.1), which assumes the unburned area contributes a negligible amount to the flood. The assumption seems justified for Spring Creek, which had 79 percent of the watershed burned, but perhaps not for Buffalo Creek (79 percent was unburned). However, flood hydrographs for Buffalo Creek indicated only one major peak in discharge and no later peaks, which may have indicated significant runoff from the unburned part of the watershed. Post-fire floods are listed in table 3.4 along with the I_{30} values for both Buffalo and Spring Creeks. Often, rainfall events created floods on Buffalo Creek but not on Spring Creek, and vice versa. For example, see 2 August and 26 August 1997. However, data are listed for both watersheds, even though the corresponding event in the other watershed did not meet the criterion for a flood.

Results

Discharge Rating Curve

The discharge rating curve for these steep channels can be modeled as critical flow. For critical flow, the cross-sectional mean velocity is given by

$$v = (gh)^{\frac{1}{2}} = \left(g\frac{A}{w}\right)^{\frac{1}{2}} , \qquad \textbf{eq. 3. 1}$$

where g is the acceleration of gravity, A is the cross-sectional area, h is the mean depth above the bed, and w is the top width. Discharge for this critical flow model is then given by

$$Q = \left(g\frac{A^3}{w}\right)^{\frac{1}{2}} . \qquad \textbf{eq. 3. 2}$$

Discharges predicted by the critical flow model are plotted against measured discharges for both Buffalo and Spring Creeks in figure 3.1. Discharges can be predicted in Spring Creek as a function of mean depth by using the cross-sectional area and top width for the cross section at the gaging station (table 3.5). Measured discharges in Spring Creek fit the critical-flow model better than discharges measured in Buffalo Creek. The slope of the regression line between the measured discharge and discharge predicted by the critical flow model should be 1.00 for perfect

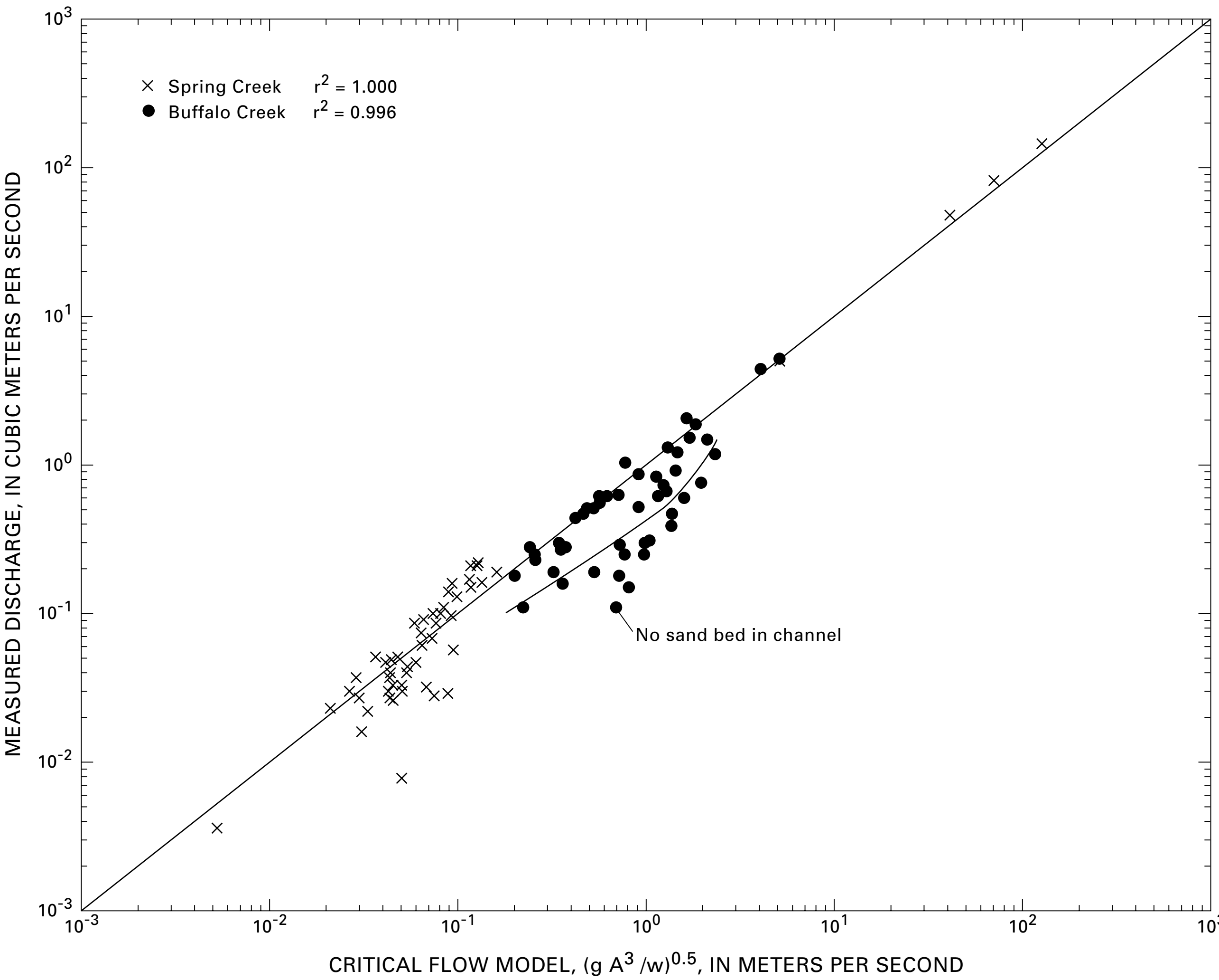


Figure 3.1. Measured discharges in Buffalo and Spring Creeks compared with those predicted by the critical flow model $Q = (g \cdot A^3/w)^{0.5}$, where g = 9.8 m/s^2, A = cross sectional area (m^2), and w = top width (m).

agreement. For Spring Creek, the slope is 1.15±0.01 (±95 percent confidence limits), and for Buffalo Creek, the slope is 0.88±0.02. The agreement is good because the data span five orders of magnitude and the large discharges have a large "influence" in the linear regression, while most of the measurements at low flow have more variability, which is exaggerated by plotting the data on a log-log plot (fig. 3.1). However, some of the variability in the Buffalo Creek data is because two different bed regimes are present. One regime was when the channel was filled with sand after a flood event and the other regime was when essentially no sand was present (below the broken line in fig. 3.1) after a prolonged period of steady flow that eroded and transported the sand out of the channel and into the North Fork of the South Platte River.

Rainfall--Runoff Relation

In Spring Creek after the wildfire, the runoff (expressed as unit-area peak discharge) was related to the rainfall intensity. This relation appears to have a change in slope at about I_{30} = 10 mm/h (fig. 3.2). This change may be caused by relative storm size, threshold intensity, or both. One possibility is that some of the discharge measurements made at the mouth of Spring Creek may represent the effect of rainstorms smaller in size than the Spring Creek watershed and, thus, the storms may have affected only a few sub watersheds. The unit-area peak discharge calculated using the drainage area of the Spring Creek watershed would, therefore, be less than the actual unit-area peak discharge. The effect may be greatest for low intensity storms, if low intensities correspond to smaller-sized rainstorms; unfortunately, no research has been done to establish this possible correspondence (Nolan Doesken, oral commun., 2000). Another possible explanation is that rainfall intensities greater than 10 mm/h may exceed the average infiltration rate of the watershed such that runoff is dominated by sheet flow that produces floods. A similar threshold intensity was reported by Mackay and Cornish (1982) for watersheds on the Bega Batholith in New South Wales. In the Spring Creek watershed, several events in 1999 and 2000 corresponding to intensities between 10 and 30 mm/h (fig. 3.2) produced unit-area peak discharges less than most of those in 1997, which suggests that the threshold of critical intensity may be increasing and might explain the decrease in extreme floods in 1999 and 2000 (table 3.4). For example, in 1997, an I_{30} of about 19 mm/h produced a unit-area peak discharge of 0.31 $m^3/s/km^2$, whereas in 2000 a similar rainfall intensity produced a unit-area peak discharge of only 0.0031 $m^3/s/km^2$, corresponding to a 100-fold decrease. Also in 1997, an I_{30} of about 50 mm/h produced a unit-area peak discharge of 6.6 $m^3/s/km^2$, whereas in 2000 a comparable rainfall intensity produced a unit-area peak discharge of only 0.11 $m^3/s/km^2$, or a 60-fold decrease. Some data from the Barrett Fire (Sinclair and Hamilton, 1955) and Johnstone Peak Fire (Krammes and Rice, 1963; Doehring, 1968) in the San Grabriel Mountains of Southern California are also plotted in figure 3.2. Terrain and bedrock in these mountains are similar to Buffalo and Spring Creeks, steep and granitic, but the vegetation is predominately chaparral.

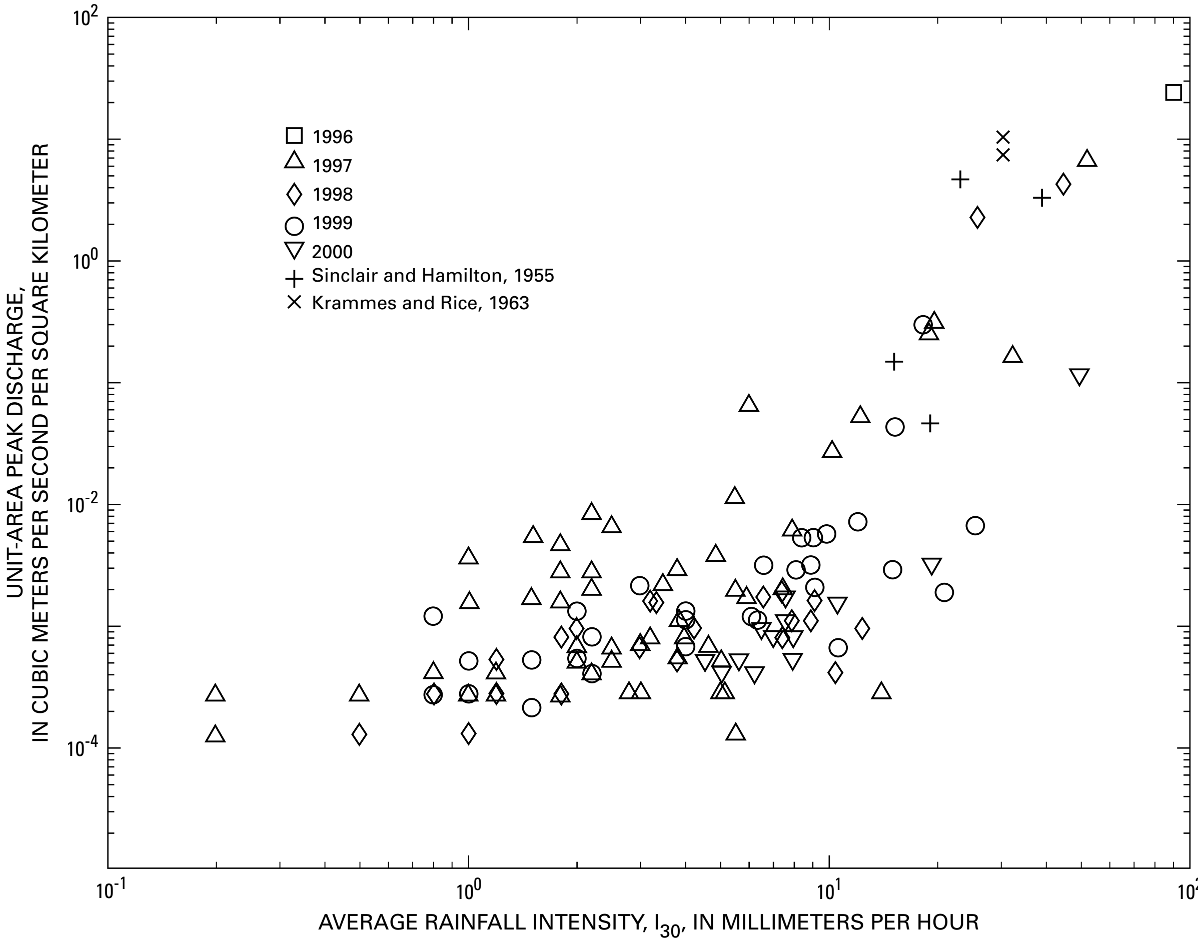


Figure 3.2. Relation between unit-area peak discharge and the 30-minute maximum rainfall intensity, I_{30}. Discharges were measured at the gage at the mouth of the Spring Creek watershed, and the rainfall intensity was the average of the I_{30}-intensities at the Scraggy Ranch gage and at the Spring Creek gage.

Table 3.1. Summary of discharge measurements for Buffalo Creek, 1997-2000

[No., number of the discharge measurement reported on the U. S. Geological Survey's form 9-207 for the gage site about 600 m upstream from the mouth; other measurements were made using Price-AA current meter at 0.6 depth and various types of surface floats and multiplying the surface velocity by 0.86 to estimate the depth-averaged mean velocity (Rantz and others, 1982); mean velocity is discharge/area; mean depth is area/width; SA, slope area indirect method to determine peak discharge; SC, specific conductance (microsiemens/centimeter); MDT, Mountain Daylight Time; MST, Mountain Standard Time; m, meter; m^2, square meter; m/s, meter per second; m^3/s, cubic meter per second]

No.	Date	Width (m)	Mean depth (m)	Area (m^2)	Slope	Mean velocity (m/s)	Gage height (feet)	Discharge (m^3/s)	Comments
						1997			
	3-20-97	4.1	0.063	0.26	0.0093	0.68	not measured	0.18	Measured before gage was installed; used slope from June 1997 survey; at 79 m upstream from the mouth.
1	5-22-97	6.2	0.095	0.59	--	0.98	4.20	0.56	--
	7-01-97	8.4	0.074	0.62	0.0093	0.82	5.0	0.51	Used slope from June 1997 survey; at 79 m upstream from the mouth; measured near noon.
	7-14-97	9.3	0.053	0.49	0.010	0.55	4.68	0.27	Surface velocity measurement at 79 m upstream from the mouth.
	7-14-97	5.6	0.064	0.36	0.011	0.69	4.68	0.25	Surface velocity measurement at 480 m upstream from the mouth.
2	7-15-97	4.1	0.071	0.29	--	0.22	4.65	0.28	--
SA	7-29-97	12.9	0.91	11.7	0.016	2.6	8.4	30.5	Indirect measurement.
	8-19-97	7.3	0.070	0.51	0.011	0.86	5.14	0.44	Measured at 72 m upstream from the mouth.
3	8-27-97	4.9	0.100	0.49	--	1.04	4.94	0.51	--
	9-01-97	5.0	0.096	0.48	0.013	0.98	4.8	0.47	Measured at 90 m upstream from the mouth; 1330-1354 MDT.
4	10-08-97	3.2	0.088	0.28	--	0.85	4.61	0.23	SC=166.
	11-03-97	6.3	0.094	0.59	0.015	1.1	5.18	0.62	Measured at 79 m upstream from the mouth; 1128-1156 MST.
	11-03-97	8.0	0.085	0.68	0.013	0.91	5.13	0.62	Measured at 79 m upstream from the mouth; 1353-1430 MST.
	11-07-97	7.5	0.11	0.86	0.014	1.0	5.17	0.87	--
						1998			
5	4-27-98	10.2	0.12	1.21	--	1.08	5.92	1.31	SC=95.
	5-09-98	8.0	0.16	1.3	0.015	1.6	5.89	2.1	Measured at 480 m upstream from the mouth.
6	5-11-98	9.4	0.15	1.41	--	1.09	5.70	1.53	SC=84.
7	5-20-98	6.5	0.20	1.31	--	1.43	4.93	1.88	--
8	6-03-98	5.5	0.25	1.36	--	1.09	4.03	1.48	SC=71.
9	6-23-98	4.9	0.21	1.01	--	0.91	3.76	0.92	SC=62.
	7-22-98	6.9	0.14	0.98	0.015	0.63	3.76	0.62	Measured at 190 m upstream from the mouth; gravel bed with almost no sand.
10	7-24-98	4.6	0.20	0.92	--	0.73	3.62	0.67	Lowered orifice; SC=91.

Table 3.1. (Continued) Summary of discharge measurements for Buffalo Creek, 1997-2000

No.	Date	Width (m)	Mean depth (m)	Area (m^2)	Slope	Mean velocity (m/s)	Gage height (feet)	Discharge (m^3/s)	Comments
	8-07-98	8.3	0.096	0.80	0.014	1.3	5.57	1.0	Measurement was at 480 m upstream from the mouth.
11	8-27-98	4.8	0.13	0.63	--	0.99	4.85	0.63	--
12	10-08-98	3.0	0.12	0.35	--	0.79	3.80	0.28	SC=157.
	10-17-98	2.7	0.12	0.32	0.0073	0.94	3.76	0.30	Surface velocity was measured over a distance of 7 m at 480 m upstream from the mouth.
13	11-24-98	2.8	0.11	0.31	--	0.62	3.65	0.19	SC=160.
						1999			
14	3-24-99	2.1	0.10	0.22	--	0.50	3.49	0.11	--
15	4-21-99	2.7	0.12	0.33	-	0.48	3.46	0.16	--
16	5-05-99	7.2	0.16	1.17	--	1.05	3.98	1.22	SC=90.
17	5-19-99	3.6	0.22	0.78	--	1.08	3.98	0.84	SC=89.
18	5-25-99	11.3	0.24	2.68	--	1.66	5.66	4.45	SC=60.
	5-26-99	13.7	0.24	3.33	0.015	1.6	5.51	5.20	Surface velocity was measured at 190 m upstream from the mouth.
19	6-09-99	5.5	0.26	1.45	--	0.82	3.69	1.19	SC=82.
20	7-01-99	6.1	0.22	1.34	--	0.57	3.30	0.76	SC=97.
21	7-20-99	3.3	0.26	0.86	--	0.55	3.12	0.47	--
22	8-17-99	6.4	0.16	1.00	--	0.73	3.52	0.73	SC=103.
23	9-02-99	5.8	0.14	0.79	--	0.65	3.35	0.52	SC=129.
24	10-13-99	2.9	0.19	0.56	--	0.46	3.18	0.25	SC=142.
						2000			
25	3-27-00	2.4	0.17	0.41	--	0.48	3.07	0.19	SC=140.
26	4-18-00	2.8	0.24	0.68	--	0.46	3.16	0.31	SC=111.
27	4-20-00	2.9	0.23	0.66	--	0.46	3.18	0.30	--
28	5-16-00	2.8	0.29	0.81	--	0.48	3.16	0.39	SC=87.
	6-04-00	4.0	0.15	0.60	0.0026	0.48	3.10	0.29	--
29	6-22-00	2.5	0.20	0.51	--	0.34	2.93	0.18	SC=110.
30	6-28-00	2.2	0.27	0.60	--	0.42	3.44	0.25	SC=102.
31	8-03-00	4.3	0.24	1.04	--	0.58	3.76	0.60	SC=71.
32	8-31-00	2.6	0.22	0.56	--	0.27	3.35	0.15	SC=140.
33	10-10-00	2.4	0.20	0.49	--	0.23	3.38	0.11	SC=154.

Table 3.2. Summary of discharge measurements for Spring Creek, 1997-2000

[No., number of the discharge measurement reported on the U. S. Geological Survey's form 9-207 for the gage site about 1500 m upstream from the mouth; other measurements were made using Price-AA current meter at 0.6 depth and various types of surface floats and multiplying the surface velocity by 0.86 to estimate the depth-averaged mean velocity (Rantz and others, 1982); nm, not measured; mean depth is area/width; mean velocity is discharge/area; SA, slope area indirect method to determine peak discharge; SC, specific conductance (microsiemens/centimeter); MDT, Mountain Daylight Time; MST, Mountain Standard Time; m, meter; m^2, square meter; m/s, meter per second; m^3/s, cubic meter per second]

No.	Date	Width (m)	Mean depth (m)	Area (m^2)	Slope	Mean velocity (m/s)	Gage height (feet)	Discharge (m^3/s)	Comments
						1997			
1	4-21-97	1.00	0.045	0.045	--	0.60	4.02	0.027	Installed gage; SC = 209.
2	5-19-97	0.76	0.050	0.038	--	0.79	4.05	0.030	--
3	7-15-97	0.91	0.061	0.056	--	0.48	3.96	0.027	--
4	8-26-97	1.22	0.045	0.055	--	0.93	4.20	0.051	--
	6-28-97	0.61	0.064	0.039	0.04	0.41	4.75	0.016	Parshall flume at mouth; 1315-1415 MDT.
	7-02-97	0.61	0.034	0.021	0.04	0.37	4.07	0.0078	Parshall flume at mouth; 1100-1300 MDT.
	7-11-97	0.61	0.021	0.013	0.026	0.28	4.23	0.0036	Parshall flume at mouth; 1735-1825 MDT.
SA	7-29-97	8.7	0.33	2.9	0.041	1.7	5.41	5.0	Used Cowan's (1956) method of estimating Manning's n = 0.055.
	8-03-97	0.61	0.067	0.041	0.030	0.54	4.20	0.022	Parshall flume at mouth; 1400-1500 MDT.
	8-05-97	0.61	0.089	0.054	0.032	0.63	4.30	0.034	Parshall flume at mouth; 1900-1944 MDT.
SA	8-31-97	--	---	--	--	--	13.4	180	USGS Colorado District.
	8-31-97	12	2.2	27	0.04	5.4	13.4	140	Estimated slope was 0.04. Used Cowan's (1956) method for estimating Manning's n = 0.055.
	9-15-97	1.40	0.046	0.065	0.032	0.61	4.42	0.040	Surface velocity was measured at 13 verticals at mouth at 1130 MDT.
	10-08-97	0.85	0.041	0.035	0.027	0.66	4.11	0.023	Surface velocity was measured at 7 verticals at mouth.
5	10-08-97	1.07	0.042	0.045	--	0.82	4.11	0.037	SC = 195.
						1998			
6	3-24-98	2.28	0.052	0.118	--	0.93	4.44	0.11	SC = 210.
7	3-26-98	2.53	0.060	0.151	--	1.14	4.34	0.17	--
8	4-27-98	2.13	0.084	0.178	--	1.05	4.34	0.19	SC = 175.
	5-03-98	3.0	0.056	0.17	--	1.2	4.30	0.21	Surface velocity was measured at about 1500 MDT.
	5-17-98	2.4	0.063	0.15	--	1.0	4.20	0.15	Surface velocity was measured at gage at about 1510 MDT.

Table 3.2. (Continued) Summary of discharge measurements for Spring Creek, 1997-2000

No.	Date	Width (m)	Mean depth (m)	Area (m^2)	Slope	Mean velocity (m/s)	Gage height (feet)	Discharge (m^3/s)	Comments
	5-21-98	2.0	0.063	0.126	--	1.0	4.2	0.13	Surface velocity was measured at gage at about 1200 MDT.
	5-21-98	2.7	0.050	0.134	0.030	1.2	4.2	0.16	Surface velocity was measured in a flume constructed of rocks at the mouth at about 1300 MDT.
9	6-08-98	2.04	0.052	0.107	--	0.80	4.09	0.086	--
	6-26-98	1.7	0.054	0.091	0.023	1.0	3.92	0.091	Surface velocity was measured at gage at 1223 MDT.
	6-26-98	2.0	0.047	0.094	0.025	0.79	3.90	0.074	Surface velocity was measured in a flume constructed of rocks at the mouth at 1725 MDT.
SA	7-09-98	10.5	1.2	12.2	0.04	3.9	8.75	48	Used Cowan's (1956) method of estimating Manning's n = 0.055. USGS Colorado District indirect measurement was 58 $m^3 s^{-1}$.
10	7-14-98	1.34	0.058	0.078	--	1.10	4.43	0.086	--
SA	7-31-98	11.1	1.6	17.8	0.04	4.6	10.4	82	High water was estimated to be 9 July high water plus 0.5 m. Used Cowan's (1956) method of estimating Manning's n = 0.055;.
	8-05-98	2.7	0.048	0.130	0.034	1.1	4.67	0.14	Surface velocity was measured 100 m below gage at 1805 MDT.
11	9-11-98	1.49	0.075	0.111	--	0.51	nm	0.057	--
	10-21-98	1.3	0.068	0.089	--	0.76	nm	0.068	Surface velocity was measured 21 m upstream from gage at 0925 MDT and water level was 0.03 m below gage orifice.
12	11-24-98	1.2	0.053	0.063	--	0.52	nm	0.033	SC =202.
						1999			
	2-24-99	1.3	0.049	0.064	0.023	0.77	nm	0.049	Used pieces of ice as floats over a 3 m reach.
13	3-23-99	0.94	0.096	0.091	--	0.32	4.30	0.029	Sandbags put in channel at gage.
14	4-21-99	0.91	0.068	0.062	--	0.48	4.31	0.030	SC =207.
15	5-05-99	2.35	0.069	0.163	--	1.00	4.48	0.162	
	5-05-99	2.0	0.075	0.15	~0.025	1.8	4.42	0.22	Used surface floats to measure velocity over a 10 m reach at 30 m above the gage at 1745 MDT.

Table 3.2. (Continued) Summary of discharge measurements for Spring Creek, 1997-2000

No.	Date	Width (m)	Mean depth (m)	Area (m^2)	Slope	Mean velocity (m/s)	Gage height (feet)	Discharge (m^3/s)	Comments
	5-15-99	1.40	0.065	0.092	0.027	1.1	4.09	0.10	Measured velocity using surface floats over a 3 m reach at the mouth at 1100 MDT.
	5-26-99	2.0	0.070	0.141	0.034	1.5	4.27	0.21	Measured velocity using surface floats over a 3.6 m reach at the mouth at 1545 MDT.
16	6-09-99	1.80	0.064	0.116	--	0.84	4.18	0.097	SC = 191.
17	7-01-99	1.34	0.059	0.079	--	0.59	4.43	0.047	Pressure transducer was installed. SC = 200.
18	7-28-99	1.16	0.068	0.079	--	0.77	4.43	0.061	SC = 210.
19	9-02-99	2.16	0.052	0.113	--	0.88	4.34	0.100	Sand bags were added to the control. SC = 205.
20	10-13-99	1.52	0.047	0.071	--	0.72	4.26	0.051	SC = 210.
						2000			
21	3-27-00	0.94	0.069	0.065	--	0.62	4.33	0.040	SC = 204.
	5-02-00	0.95	0.058	0.055	0.026	0.85	4.42	0.047	Mouth; 1315 MDT.
22	4-18-00	1.10	0.063	0.069	--	0.64	4.34	0.044	SC = 204.
23	5-16-00	1.22	0.050	0.061	--	0.49	4.32	0.030	SC = 210.
24	6-22-00	1.19	0.053	0.063	--	0.41	4.33	0.026	SC = 219.
25	8-02-00	0.76	0.093	0.071	--	0.45	4.24	0.032	SC = 213.
26	8-31-00	1.07	0.079	0.085	--	0.33	4.35	0.028	SC = 221.
27	10-10-00	1.07	0.055	0.059	--	0.63	4.35	0.037	SC = 218.

Table 3.3. Rainfall intensity and peak discharges for the Spring Creek watershed, 1997-2000

[I_{30}, maximum 30-minute rainfall intensity; na, not applicable; mm/h, millimeter per hour; m^3/s cubic meter per second; $m^3/s/km^2$, cubic meter per second per square kilometer]

Day Month	I_{30} (mm/h) Long Scraggy Ranch	I_{30} (mm/h) Spring Creek above mouth	I_{30} (mm/h) Average	Peak discharge Above back-ground (m^3/s)	Peak discharge Per unit-area ($m^3/s/km^2$)
			1996		
12 July	na	na	90	510	24
			1997		
6 June	9.75	0.50	5.1	0.0057	0.00027
6 June	16.75	11.25	14.0	0.0057	0.00027
7 June	7.00	0.50	3.8	0.011	0.00052
7 June	0.50	8.75	4.6	0.014	0.00066
8 June	2.50	0.00	1.2	0.0057	0.00027
8 June	1.00	1.00	1.0	0.0057	0.00027
8 June	2.00	0.50	1.2	0.0085	0.00040
8 June	3.00	2.50	2.8	0.0057	0.00027
9 June	0.50	0.00	0.2	0.0028	0.00013
9 June	0.50	3.50	2.0	0.011	0.00052
9 June	1.00	0.50	0.8	0.0085	0.00040
12 June	2.50	1.50	2.0	0.011	0.00052
12 June	0.50	0.50	0.5	0.0057	0.00027
13 June	1.50	1.00	1.2	0.0	0.0
13 June	0.00	7.50	3.8	0.023	0.0011
14 June	1.50	2.00	1.8	0.10	0.0047
15 June	2.50	1.00	1.8	0.062	0.0029
16 June	0.00	0.50	0.2	0.0057	0.00027
17 June	0.00	8.00	4.0	0.017	0.00080
18 June	13.25	1.50	7.4	0.042	0.0020
21 June	6.00	6.00	6.0	1.4	0.066
21 June	3.00	0.00	1.5	0.034	0.0016
21 June	3.00	2.00	2.5	0.14	0.0066
21 June	2.50	0.50	1.5	0.11	0.0052
23 June	1.00	1.00	1.0	0.074	0.0035
24 June	3.00	1.50	2.2	0.18	0.0085
28 July	14.25	10.25	12.2	1.1	0.052
29 July	25.00	13.25	19.1	5.0	0.24
30 July	7.50	3.00	5.0	0.011	0.00052
31 July	40.75	24.00	32.4	3.6	0.17
31 July	7.50	3.50	5.5	0.040	0.0019
1 Aug.	0.50	0.50	0.5	0.0057	0.00027
2 Aug.	4.50	0.50	2.5	0.014	0.00066
4 Aug.	3.00	1.50	2.2	0.0085	0.00040
4 Aug.	2.00	1.50	1.8	0.0057	0.00027
4 Aug.	2.00	3.00	5.5	0.0028	0.00013
5 Aug.	5.50	0.50	3.0	0.0057	0.00027
5 Aug.	5.50	4.50	5.0	0.0057	0.00027
			1997		
5 Aug.	4.00	7.00	5.5	0.23	0.011
6 Aug.	3.00	1.00	2.0	0.014	0.00066
7 Aug.	5.00	1.50	3.2	0.017	0.00080
9 Aug.	11.75	8.75	10.2	0.57	0.027
11 Aug.	0.00	7.50	3.8	0.059	0.0028
12 Aug.	0.00	9.75	4.9	0.079	0.0037
12 Aug.	11.25	4.50	7.9	0.13	0.0061
13 Aug.	0.50	0.00	0.2	0.0057	0.00027
17 Aug.	1.00	2.50	1.8	0.051	0.0024
17 Aug.	4.00	1.00	2.5	0.011	0.00052
17 Aug.	1.50	3.00	2.2	0.042	0.0020
17 Aug.	1.00	2.50	1.8	0.034	0.0016
19 Aug.	1.00	5.00	3.0	0.014	0.00066
22 Aug.	1.50	5.50	3.5	0.045	0.0021
24 Aug.	10.75	1.00	5.9	0.037	0.0017
25 Aug.	2.00	2.50	2.2	0.059	0.0028
25 Aug.	0.50	0.50	0.5	0.0057	0.00027
25 Aug.	2.00	1.00	1.5	0.037	0.0017
26 Aug.	0.00	2.00	1.0	0.031	0.0015
26 Aug.	28.00	11.25	19.6	6.6	0.31
28 Aug.	2.00	1.00	1.5	0.034	0.0016
31 Aug.	15.75	88.00	51.9	140	6.6
	Stream gage was damaged.				
			1998		
8 June	6.50	1.00	3.8	0.011	0.00052
8 June	4.00	2.00	3.0	0.014	0.00066
14 June	4.50	13.75	9.1	0.034	0.0016
20 June	0.50	2.00	1.2	0.011	0.00052
21 June	1.00	0.00	0.5	0.0028	0.00013
21 June	0.50	1.50	1.0	0.0028	0.00013
30 June	1.00	0.50	0.8	0.0057	0.00027
8 July	17.25	7.50	12.4	0.020	0.00094
9 July	44.25	7.00	25.6	48	2.3
	Stream gage was damaged from 9-11 July.				
21 July	12.25	5.50	8.9	0.023	0.0011
22 July	12.25	2.50	7.4	0.040	0.0019
22 July	3.50	3.00	3.2	0.034	0.0016
28 July	5.50	10.25	7.9	0.023	0.0011
28 July	2.50	1.00	1.8	0.0057	0.00027

Table 3.3. (Continued) Rainfall intensity and peak discharges for the Spring Creek watershed, 1997-2000

	I_{30} (mm/h)			Peak discharge	
Day Month	Long Scraggy Ranch	Spring Creek above mouth	Average	Above back-ground (m^3/s)	Per unit-area ($m^3/s/km^2$)
			1998		
28 July	13.25	0.00	6.6	0.037	0.0017
31 July	61.00	28.50	44.8	82	3.9
Stream gage was not functioning from 1 August to 17 August					
17 Aug.	2.00	1.50	1.8	0.017	0.00080
18 Aug.	2.00	0.50	1.2	0.0057	0.00027
24 Aug.	10.75	4.00	7.4	0.017	0.00080
25 Aug.	2.00	2.00	2.0	0.020	0.00094
31 Aug.	15.75	5.00	10.4	0.0085	0.00040
			1999		
9 June	5.50	2.50	4.0	0.028	0.0013
9 June	4.50	3.50	4.0	0.014	0.00066
10 June	4.00	4.00	4.0	0.014	0.00066
10 June	12.25	6.00	9.1	0.042	0.0020
11 June	4.50	7.75	6.1	0.025	0.0012
11 June	0.50	1.00	0.8	0.0057	0.00027
3 July	1.50	1.50	1.5	0.045	0.0021
8 July	2.50	18.75	10.6	0.014	0.00066
11 July	29.00	1.00	15.0	0.062	0.0029
14 July	3.00	0.00	1.5	0.011	0.00052
15 July	2.50	1.50	2.0	0.011	0.00052
17 July	6.50	35.00	20.8	0.040	0.0019
19 July	0.00	2.00	1.0	0.0057	0.00027
22 July	1.00	1.00	1.0	0.011	0.00052
28 July	46.75	4.00	25.4	0.14	0.0066
29 July	35.50	1.0	18.2	6.4	0.30
30 July	15.75	2.50	9.1	0.11	0.0052
31 July	9.25	10.25	9.8	0.12	0.0057
31 July	11.25	5.00	8.1	0.062	0.0029
31 July	11.75	5.00	8.4	0.11	0.0052

	I_{30} (mm/h)			Peak discharge	
Day Month	Long Scraggy Ranch	Spring Creek above mouth	Average	Above back-ground (m^3/s)	Per unit-area ($m^3/s/km^2$)
			1999		
4 Aug.	16.25	14.25	15.2	0.91	0.043
7 Aug.	0.00	13.25	6.6	0.065	0.0031
8 Aug.	14.25	1.50	7.9	0.13	0.0061
15 Aug.	10.25	2.50	6.4	0.023	0.0011
17 Aug.	12.75	11.25	12.0	0.15	0.0071
21 Aug.	1.00	0.50	0.8	0.025	0.0012
25 Aug.	16.25	1.50	8.9	0.065	0.0031
25 Aug.	3.50	2.50	3.0	0.045	0.0021
27 Aug.	4.50	0.00	2.2	0.017	0.00080
27 Aug.	4.00	4.00	4.0	0.023	0.0011
29 Aug.	1.00	3.00	2.0	0.028	0.0013
31 Aug.	1.50	1.00	2.2	0.0085	0.00040
			2000		
12 July	4.50	10.75	7.6	0.037	0.0017
16 July	31.50	67.00	49.2	2.4	0.11
17 July	34.00	4.50	19.2	0.065	0.0031
4 Aug.	1.00	5.50	6.2	0.0085	0.00040
13 Aug.	7.50	7.50	7.5	0.023	0.0011
17 Aug.	8.75	5.50	7.0	0.017	0.00080
20 Aug.	1.00	20.25	10.6	0.031	0.0015
26 Aug.	4.50	11.25	7.9	0.017	0.00080
28 Aug.	3.00	6.00	4.5	0.011	0.00052
31 Aug.	8.25	7.50	7.9	0.011	0.00052
5 Sept.	5.50	7.50	6.5	0.020	0.00094
21 Sept	8.25	3.00	5.6	0.011	0.00052
24 Sept.	3.50	6.50	5.0	0.0085	0.00040

Table 3.4. Post-fire flood characteristics in the watersheds burned by the Buffalo Creek Fire, 1996-2000.

[Includes floods in either watershed when the peak discharge was greater than 10 times the baseflow for June, July, and August 1997 and 1998 (table 1.1) or when the maximum 30-minute intensity, I_{30}, was greater than 10 mm/h; unit-area peak discharge, peak discharge/burned area; Ave., average; ~, estimated; na, not available; ni, no increase above baseflow; mm/h, millimeters per hour; m^3/s, cubic meter per second; $m^3/s/km^2$, cubic meter per second per square kilometer]

Date	Buffalo Creek Watershed					Spring Creek Watershed				
	I_{30} (mm/h)			Peak discharge (m^3/s)	Unit-area peak discharge ($m^3/s/km^2$)	I_{30} (mm/h)			Peak discharge (m^3/s)	Unit-area peak discharge ($m^3/s/km^2$)
	Morrison	Buffalo Creek	Ave.			Long Scraggy	Spring Creek	Ave.		
1996										
12 June	na	na	na	na	na	na	na	na	20	0.94
12 July	na	na	80.[a]	450.[c]	18	na	na	~90.[a,b]	510.[c]	24
23 Aug.	na	na	~30	40.[b]	1.6	na	na	na	30	1.4
14 Sept.	na	na	10-18[b]	5	0.2	na	na	na	7	0.33
1997										
6 June	17.75	20.75	19.2	13	0.51	16.75	11.25	14.0	0.0057	0.00027
28 July	10.75	19.75	15.2	13	0.51	14.75	10.25	12.2	1.1	0.052
29 July	15.25	15.25	15.2	30.5[d]	1.2	25.00	13.75	19.1	5.0[d]	0.24
31 July	22.25	37.00	29.6	8.3	0.32	40.75	24.00	32.4	3.6	0.17
2 Aug.	5.00	11.25	8.1	8.2	0.32	4.50	0.50	2.5	0.014	0.00066
9 Aug.	36.00	16.25	12.2	9.9	0.39	11.75	8.75	10.2	0.57	0.027
26 Aug.	14.25	8.75	11.5	0.7	0.027	28.00	11.25	19.6	6.6	0.31
31 Aug.	1.00	14.75	7.9	5.3	0.21	15.75	88.00	51.9	140.[d]	6.6
1998										
8 July	4.50	5.50	5.0	ni	ni	17.25	7.50	12.4	0.020	0.00094
9 July	1.00	5.50	3.2	ni	ni	44.25	7.00	25.6	48.[d]	2.3
31 July	10.25	50.75	30.5	gage damaged		61.00	28.50	44.8	82.[d]	3.9
31 Aug.	7.00	3.00	5.0	0.11	0.0043	15.75	5.00	10.4	0.0085	0.00040
1999										
8 July	2.50	2.50	2.5	ni	ni	2.50	18.75	10.6	0.014	0.00066
11 July	2.00	17.25	9.6	0.20	0.0078	29.00	1.00	15.0	0.062	0.0029
17 July	11.25	16.25	13.8	ni	ni	6.50	35.00	20.8	0.040	0.0019
28 July	8.75	6.00	7.4	ni	ni	46.75	4.00	25.4	0.14	0.0066
29 July	3.50	27.50	15.5	5.1	0.20	35.50	1.00	18.2	6.4	0.30
4 Aug.	7.00	6.50	6.8	0.080	0.0031	16.25	14.25	15.2	0.91	0.043
17 Aug.	0.00	0.50	0.5	ni	ni	12.75	11.25	12.0	0.15	0.0071
2000										
16 July	7.50	32.50	20.0	ni	ni	31.50	67.00	49.2	2.4	0.11
17 July	48.75	24.50	36.6	ni	ni	34.00	4.50	19.2	0.065	0.0031
20 Aug.	1.50	1.00	2.2	0.028	0.001	1.00	20.25	10.6	0.031	0.0015

[a]This is an average of the maximum one-hour intensities of 110 mm/h at Long Scraggy Ranch and 75 mm/h near the Spring Creek gage, Henz, 1998; Jarrett, 2001.

[b]Jarrett, R. D., written commun., 1996.

[c]Yates and others, 2000.

[d]Indirect discharge measurement.

Table 3.5. Geometric characteristics for the channel cross section at the Spring Creek gage

[m, meter; m^2, square meter]

Depth (m)	Area (m^2)	Width (m)	Hydraulic radius (m)	Depth (m)	Area (m^2)	Width (m)	Hydraulic radius (m)
0.00	0.00	0.00	0.0	1.16	8.78	9.91	0.83
0.030	0.037	2.74	0.014	1.22	9.38	10.03	0.87
0.061	0.14	3.66	0.038	1.28	10.00	10.15	0.91
0.091	0.26	3.90	0.066	1.34	10.62	10.27	0.95
0.12	0.38	4.05	0.093	1.40	11.25	10.39	1.00
0.15	0.50	4.30	0.12	1.46	11.89	10.52	1.04
0.18	0.64	4.63	0.14	1.52	12.53	10.58	1.08
0.21	0.79	5.00	0.16	1.58	13.18	10.67	1.12
0.24	0.95	5.36	0.18	1.65	13.83	10.73	1.16
0.27	1.11	5.68	0.19	1.71	14.49	10.79	1.20
0.30	1.29	5.94	0.21	1.77	15.15	10.85	1.25
0.34	1.48	6.19	0.24	1.82	15.81	10.94	1.28
0.37	1.67	7.28	0.23	1.89	16.48	11.00	1.33
0.40	1.90	7.50	0.25	1.95	17.16	11.06	1.36
0.43	2.13	7.71	0.27	2.01	17.83	11.13	1.40
0.46	2.37	7.92	0.29	2.07	18.52	11.19	1.44
0.49	2.61	8.14	0.31	2.13	19.19	11.28	1.47
0.52	2.86	8.32	0.34	2.19	19.89	11.34	1.51
0.55	3.12	8.53	0.36	2.26	20.58	11.40	1.55
0.58	3.38	8.72	0.38	2.32	21.27	11.46	1.58
0.61	3.65	8.78	0.41	2.38	21.98	11.56	1.62
0.64	3.92	8.84	0.43	2.44	22.69	11.61	1.65
0.67	4.19	8.90	0.46	2.50	23.39	11.67	1.69
0.70	4.46	8.96	0.48	2.56	24.11	11.73	1.72
0.73	4.74	9.02	0.51	2.62	24.82	11.80	1.76
0.76	5.02	9.08	0.53	2.68	25.55	11.89	1.79
0.79	5.30	9.17	0.56	2.74	26.27	11.95	1.82
0.82	5.57	9.24	0.58	2.80	27.00	12.01	1.86
0.85	5.85	9.30	0.60				
0.88	6.14	9.36	0.63				
0.91	6.42	9.42	0.65				
0.94	6.71	9.48	0.67				
0.98	7.00	9.54	0.70				
1.01	7.29	9.60	0.72				
1.04	7.58	9.66	0.74				
1.10	8.18	9.78	0.79				

Section 4--HILLSLOPES

Hillslopes are subdivided into interrill and rill areas. The areas were easy to distinguish after the intense rainstorms in 1996. Light yellowish-brown in appearance because they had eroded down to subsurface soils, the rill areas contrasted with the interrill areas, which were black from the color of the surface coating on the top of the gravel lag left behind as the fine material was eroded by the runoff.

Methods

Interrill

Hillslope Traps

Hillslope sediment traps were deployed in interrill areas of severely burned and unburned hillslopes of the Spring Creek watershed. Traps were installed in the burned area on north-facing and south-facing hillslopes in 1997, one year after the wildfire, and in an unburned area on north-facing and south-facing hillslopes in 1998. Four replicate traps were installed on each hillslope (south-facing, severely burned; north-facing, severely burned; south-facing, unburned; and north-facing, unburned). An interrill sediment trap consisted of a trough constructed of PVC pipe with a 1.0-m x 0.05-m collection slot. A thin metal apron was interfaced to the hillslope and connected to the slot to allow sediment to enter the trap (fig. 4.1) (Gerlach, 1967; Fitzhugh, 1992). Traps were installed perpendicular to the slope. A bucket collected sediment and water from the trough and additional buckets (connected in series) collected the water overflow from the trough. Metal edging enclosed the area of hillslope that contributed sediment to the trough. In 1997, these bounded plots were of variable size averaging 10 m^2. Starting in 1998, the enclosures were reconfigured and standardized to 5 m^2 (1 m wide x 5 m long). The collection slot was not covered, and runoff volumes reported in tables 4.1-4.4 include both runoff and direct rainfall through the slot.

Sediment and water from the four replicate traps were collected either after major storm events or as frequently as possible during the summer at all sites (tables 4.1 - 4.5). Sediment from traps on the south-facing, severely-burned hillslope was also collected during the early spring and late fall to correspond to when data were collected from rill traps on the same hillslope. On the other hillslopes, sediment was allowed to accumulate throughout the winter until the first collection of the following summer. In addition to collecting eroded sediment, 5-cm diameter x 10-cm deep soil cores from the burned and unburned, north- and south-facing hillslopes were collected to characterize the particle-size distribution of the source of sediment collected in the hillslope traps (table 4.6 and fig. 4.2).

Even using bounded plots, it is impossible to determine what percentage of the bounded area actually contributed sediment to the traps. The intensity and duration of each rainstorm is different, and the subsequent runoff transports sediment from different distances upslope into the trap. Even within a single rainstorm, runoff will transport different particle sizes for different distances downslope into the traps. Therefore, data are given as sediment flux rates, which are calculated as the mass of sediment transported across a unit contour (1 meter) per unit time (1 day). Because sediment in the traps was not collected for the same time intervals each year, the sediment flux was multiplied by the number of days in the appropriate season (122 days for the summer season, 243 days for the winter season) to estimate comparable seasonal fluxes (table 4.5).

Sediment fluxes are reported for both the summer months (June-September) and for the winter months (October-May), based on the mass of sediment collected from the hillslope traps. Because sediment samples were not collected after each storm, the data from each collection date represent the sediment moved by a variety of hillslope-transport processes.

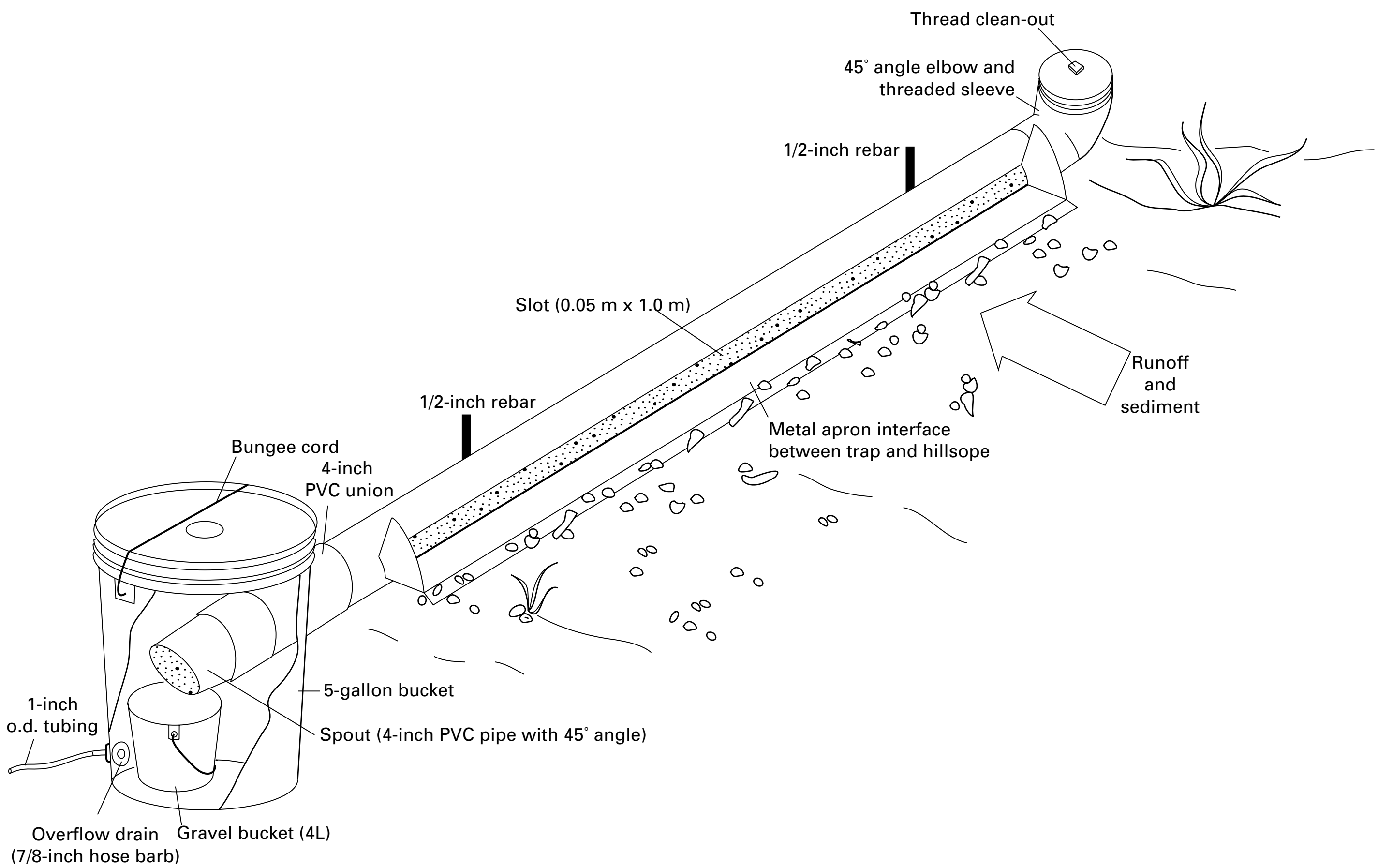


Figure 4.1. Hillslope sediment trap. During high runoffs, the gravel bucket collects mostly gravel and sand and some water, while the 5-gallon bucket, and similar 5-gallon overflow buckets connected to the overflow drain in series, collect the fine silts and clays and the remaining water. During low runoff, the gravel bucket collects gravel, sand silt, clay and water. The metal apron was interfaced to the hillslope by cutting a shallow slot (about 0.01 to 0.02 cm) for the thin metal and then driving a heavier gage sheet metal (about 1/4-inch thick, 1.0 m long and 0.06 m wide) into the hillslope on top of the thinner sheet metal forming the apron.

Particle-size Distribution

Most of the sediment collected in the hillslope sediment traps was brought back and processed in the laboratory. In the field, the total volume of water in the buckets was measured and recorded. If the water contained suspended sediment, the water was mixed in a churn splitter (Meade and Stevens, 1990) and a 1-L water subsample taken to the laboratory. The filtered sediment sample was dried at 105° C and weighed to determine the mass. To determine the particle-size distribution, the dry sediment was sieved by whole phi (Φ) intervals ($\Phi = -\log_2$ of the particle size diameter in mm; Krumbein, 1934). In addition, when sufficient dry sediment existed, a 1-gram subsample of the <0.063 mm particle size class was settled following the methods described by Guy (1969) to determine the silt (0.004-0.063 mm) and the clay (<0.004 mm) particle-size fractions. The mass of silt and clay in the water subsample was measured and added to the dry sediment sample to obtain the total particle size distribution. The median particle diameter (D_{50}) was calculated by linear interpolation. Particle-size distribution curves (fig. 4.2) were fit to the data using a cubic-spline program (R. Stallard, written commun., 1997), and 95 percent confidence limits were computed using the Student-t distribution.

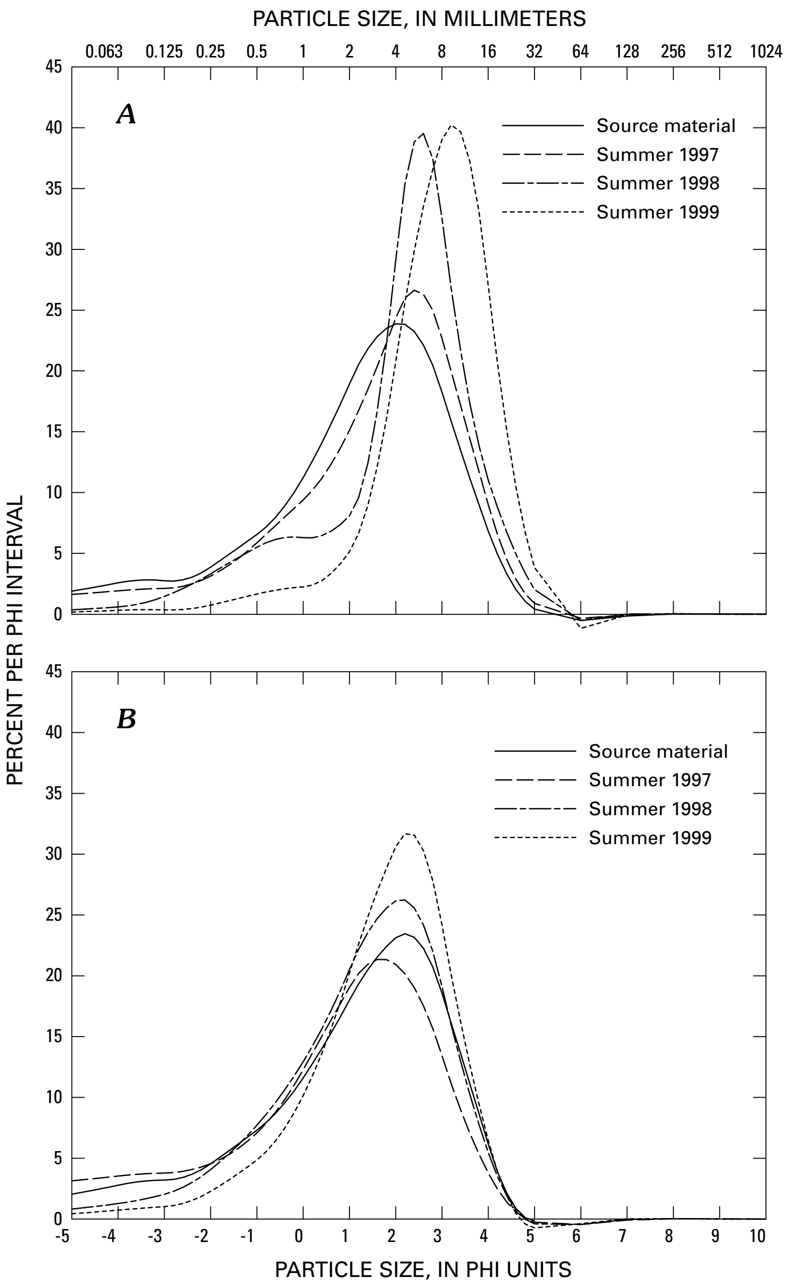


Figure 4.2. Particle-size distributions of eroded sediment (summer only) and source material A. South-facing burned hillslope. B. North-facing burned hillslope

Rills

Rills were studied on hillslopes in several subwatersheds, and on a hillslope draining directly into Spring Creek starting in 1998. Investigations focused on (1) the characteristic channel geometry and changes down the hillslope, (2) the evolution of this geometry with time, (3) the volume of sediment eroded from the rills during the first post-fire rainstorms, and (4) the sediment transport rates in rills during the year. On some hillslopes, the rills were numerous, and transects were established across these rill fields to measure rill width and depths using a carpenter's level and metric ruler. For example, figure 4.3 shows a typical rill field where transects were run approximately parallel to the elevation contours and spaced 10 m apart.

Rill Surveys

Segments of rills labelled A, B and C in figure 4.3A were surveyed in more detail and at various time intervals over two years (1998-2000) to monitor the evolution of the rills (Appendix 1). A set of five cross sections, spaced one meter apart in the downslope direction, were established on Rills A, B, and C with reference pins (4-foot long, 1/2-inch rebar, Appendix 2) at each end. Two ladders were placed on the hillside on either side of the reference pins and prevented from sliding downhill by two shorter pieces of rebar driven into the ground just downhill from a rung (fig. 4.4A). A ladder jack was put on each ladder, and a plywood platform was placed across the ladder jacks to provide a place to sit while measuring the rill cross section and to avoid disturbing the rill. Cross-sectional elevations were measured to an accuracy of 0.0005 m using an erosion bridge (fig. 4.4B) with holes spaced about 0.01 m apart. After the cross section was measured, the ladder jacks and plywood platform were repositioned on the two ladders below the next downhill cross section. Files of the cross-section measurements for the rills are on the accompanying CD where the format of the files is listed in Appendix 1.

Rill erosion during two major floods in 1996 and 1997 was estimated from aerial photographs and field measurements made in 1999. The number and spatial distribution of rills on hillslopes were counted and mapped on aerial photographs (1:3000 scale) of two subwatersheds in the Spring Creek watershed. One subwatershed, W960 (960 m upstream from the mouth of Spring Creek), is a south-facing, third-order watershed with an area of 7.0 ha and an estimated channel density of 21 km/km^2 after the fire. W1165 (1165 m upstream from the mouth of Spring Creek) is a north-facing, fourth-order watershed with an area of 3.7 ha and an estimated channel density of 48 km/km^2. Additional field measurements of rill length and cross-sectional area were made in W960, W1165, and in other subwatersheds in 1999. The eroded volumes for these two subwatersheds were calculated as the product of the mean cross-sectional area, mean rill length, and the number of rills that actually delivered sediment to the channels as shown by aerial photographs and field observations.

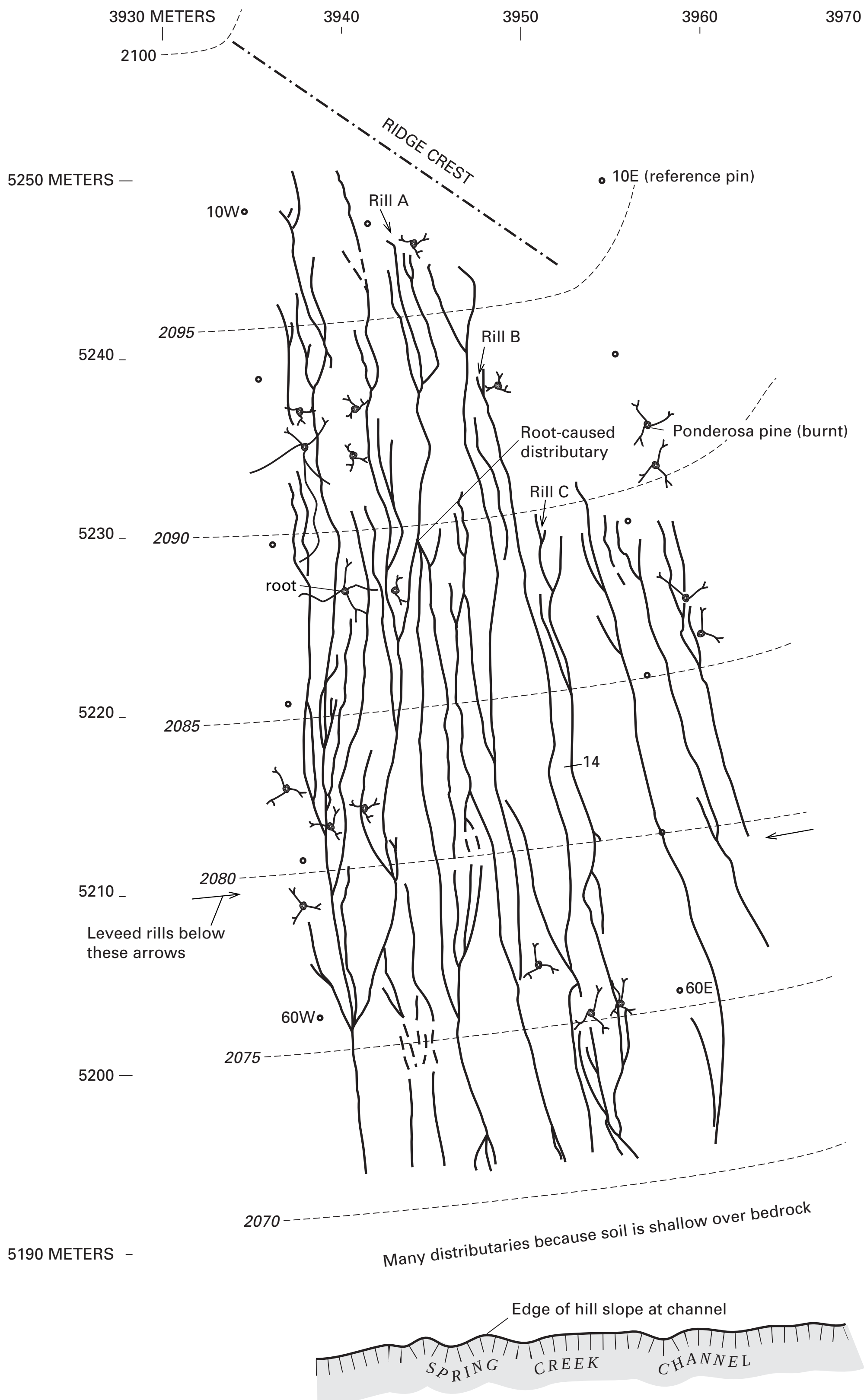


Figure 4.3. A. Map of rill field on south-facing hillslope where both interrill and rill traps have been deployed. The coordinates shown across the top and along the left edge are in the arbitrary coordinate system. Black dots are the locations of reference pins (1/2-inch rebar) for transects spaced 10 m apart. Dashed lines are contours. Cross section 1400 on Rill C is indicated as 14 on the map.

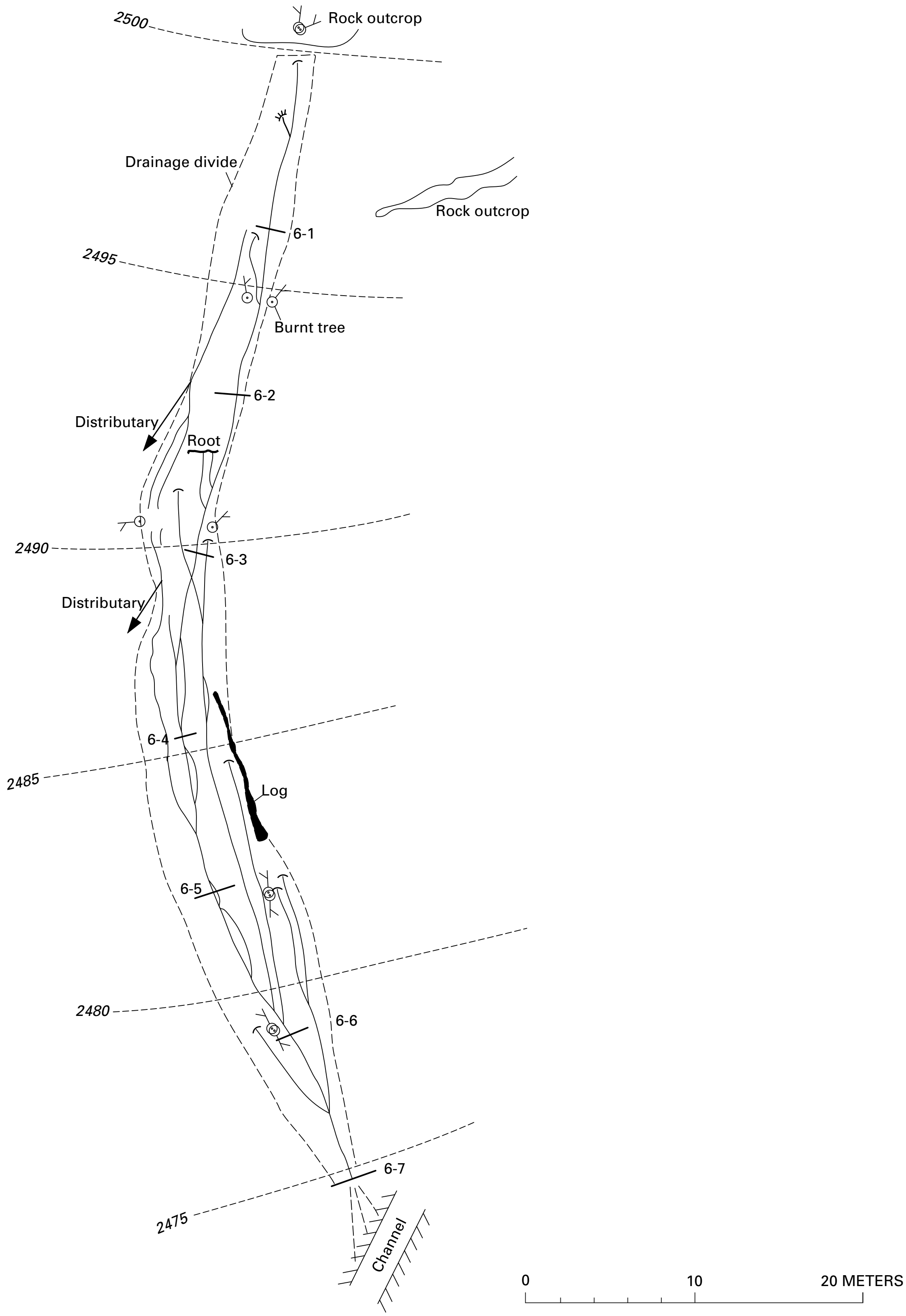
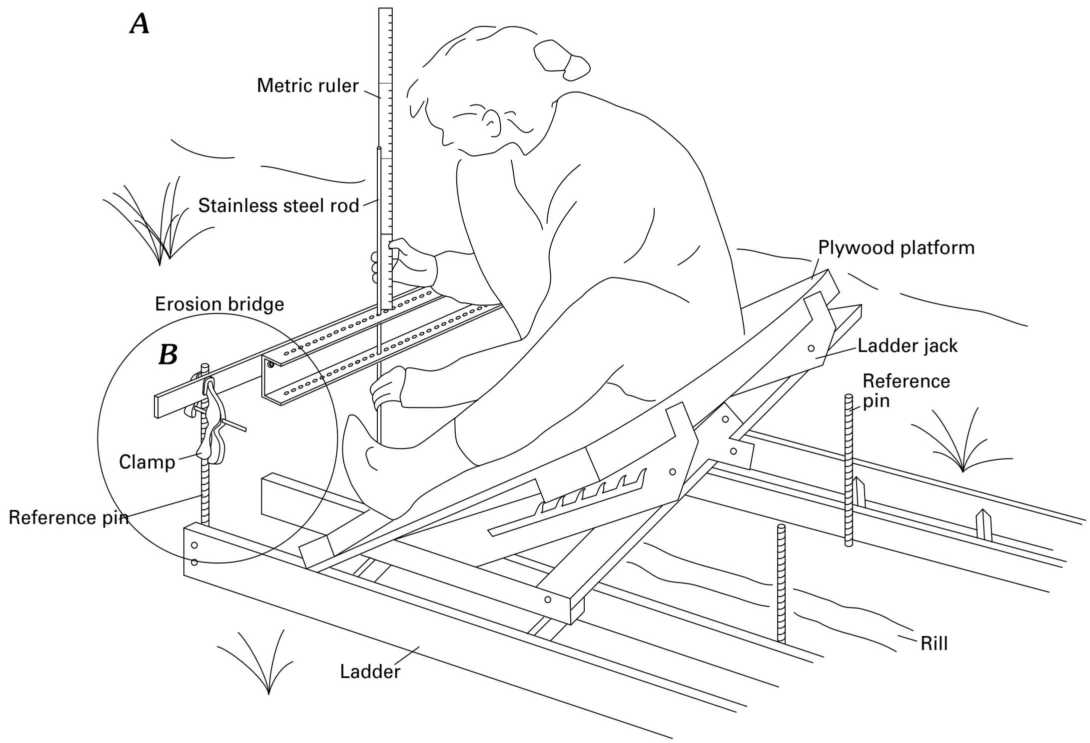


Figure 4.3 B. Map of Rill 6 (cross sections 6-1 to 6-7) on part of a northwest-facing hillslope. No arbitrary coordinates were measured in this area.



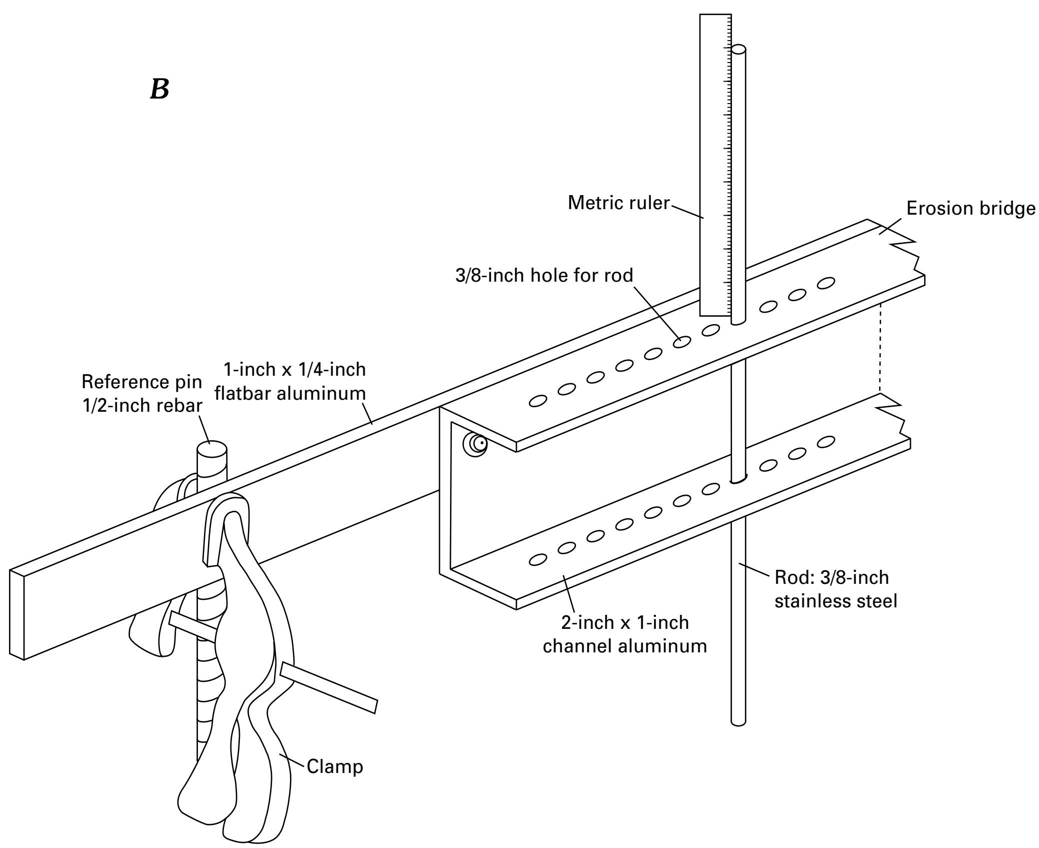


Figure 4.4. A. Equipment used for repeated measurements of rill cross sections without disturbing the rills. Normally, the reference pins were between the two ladders, with one exception shown here for the beginning of rill A. The area within the circle is enlarged in 4.4B.
B. One end of the erosion bridge, which has holes spaced about 0.010 m apart.

Rill Traps

Three rill traps (fig. 4.5) were deployed in 1998 to collect water and sediment. Each rill trap was located on a different rill and at a different distance from the beginning of the rill. Rill A represented the beginning segment of a rill with cross sections at 0, 1, 2, 3, and 4 m from the beginning of the rill and a rill trap installed just below section 4. Because this rill trap would compromise any measurements of processes in the rill downhill, a different, but similarly sized, rill (Rill B) was selected to represent processes at 4, 5, 6, 7, and 8 m downstream from the beginning of the rill. A second rill trap was installed just below cross section 8. Similarly, Rill C represented processes at 10, 11, 12, 13, and 14 m downstream from the beginning of the rill with a trap just below section 14. Water volume collected in these traps was measured and the particle-size distributions were determined by sieving on a RoTap for 15-20 minutes, weighing, and reporting by whole phi sizes (Guy, 1969). Because the area contributing to a rill was not known, sediment transport in the rills is expressed as a flux (kg/m) of sediment mass across a unit contour width (table 4.7).

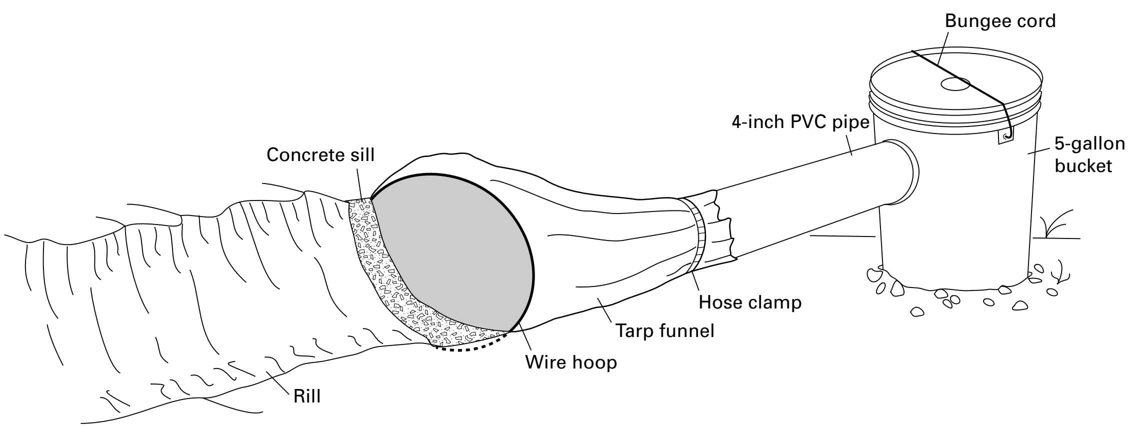


Figure 4.5. Rill trap. One end of the tarp was put under the concrete sill, which was flush with the bottom and sides of the rill. The tarp was folded over the wire hoop and secured with a screw through the folds to make a funnel. At the other end, the tarp was wrapped around the 4-inch PVC pipe and secured with a hose clamp. The 5-gallon bucket was identical to those used for the hillslope sediment traps and was linked to overflow buckets.

Results

Interrill

Sediment Flux

Estimates of the pre-fire erosion rates were made by measuring the summer sediment flux on north- and south-facing unburned hillslopes in 1998 and 1999. The average flux was 0.14 kg/m (Martin and Moody, 2001) and was similar to sediment fluxes (0.0-1.0 kg/m) measured in other unburned areas of the Colorado Front Range (Bovis, 1974; Morris, 1983; Morris and Moses, 1987; Welter, 1995).

Measurements of interrill erosion rates during the first year after the wildfire (1997), indicated more sediment was eroded from north- than from south-facing severely burned hillslopes. The average sediment-flux rate during the summer of 1997 was 0.047 kg/m/d from north-facing and 0.0077 kg/m/d from south-facing hillslopes (table 4.5). These values are minimal estimates of the sediment flux because the 1997 study began in late July, missed the sediment transport by rainfall events in June and early July, and because the rainstorm on 31 August 1997 overwhelmed the sediment traps and only part of the eroded sediment was collected on the north-facing hillslope. The total sediment fluxes for the summer of 1997 (>5.7 and 0.94 kg/m; table 4.5 and fig. 4.6) are similar to fluxes (2.9-4.0 kg/m) reported by Morris and Moses (1987) within the first year after another wildfire in the Colorado Front Range.

Average interrill erosion rates on the north- and south-facing burned hillslopes decreased during the second, third, and fourth summers after the wildfire (1998, 1999, and 2000). This decrease was not a result of less precipitation, because when the erosion is normalized by the rainfall, the severely burned north-facing slopes still produced significantly more sediment per millimeter of rainfall in 1997 than in 1998, 1999, or 2000 (fig. 4.6C). During the second summer (1998), the average sediment flux was 0.22 kg/m or about twice the pre-fire erosion flux, and during the third and fourth summers after the wildfire, the average flux was 0.11 and 0.066 kg/m, similar to pre-fire erosion rates (table 4.5).

The flux of sediment from the north-facing, burned hillslope was greater than from the south-facing, burned hillslope through the summer of 1998. We hypothesize that the pre-fire vegetation density on the north-facing slope may account for this behavior. The fuel loading on the north-facing hillslopes (mainly densely spaced Douglas-fir with a thick litter and duff layer) was greater than on the south-facing hillslope and consequently the soils on the burned north-facing hillslopes were more water-repellent than on the south-facing hillslopes (Jeff Bruggink, written commun., 1997; for a more complete discussion of fire-induced water repellency see DeBano, 1969; Debano and other, 1977, and Giovannini and others, 1983). The greater water repellency on the north-facing, burned hillslopes probably created greater runoff that, in turn, caused greater erosion. Also, the thick litter and duff layer on the north-facing hillslopes probably held sediment that was easily mobilized once the litter and duff were burned (Peter Wohlgemuth, written commun., 1999). As herbaceous ground cover grows, the sediment is increasingly stabilized, and the runoff decreases leading to decreases in sediment flux.

Particle-size Distribution

Coarser particle sizes were collected in the runoff from the burned hillslopes during the summer of 1999 than during the summer of 1997 or 1998. The median diameter ($D_{50,}$ tables 4.1 and 4.2) of the sediment collected from the runoff on the south-facing hillslope in 1999 (8.4 mm) was larger than from the north-facing hillslopes (4.1 mm). Two hypotheses could explain the shift to coarser particle sizes. One hypothesis is that the coarsening may be the result of a diminished supply of the finer-grained material. Some of the finer material was eroded from the watershed during the 1996 storms after the wildfire, as evidenced by post-flood deposits of ash and fine-grained sediment in Strontia Springs Reservoir and downstream from the Strontia Springs Dam. The erosion is also evident in 1997, by the amount of fine sediment collected in the hillslope traps (see 1997 dashed curve in fig. 4.2A, tables 4.1-4.4). An alternative hypothesis is that there may be a preferential transport of coarser material with time after the wild fire, possibly by the dry ravel process (the transport of surface material by gravity and not by flowing water; Krammes, 1960, 1965). In this climate, dry ravel is mainly triggered by wind and disturbance by fauna (deer, lizards, snakes, crickets, grasshoppers, and mice, some of which we inadvertently caught in our hillslope sediment traps). Field observations indicated that as the surfaces of both the unburned hillslopes and burned hillslopes dried out, it became increasingly difficult to walk on the surface without slipping and sliding because coarse-grained material (>4 mm diameter) was easily detached and rolled on the more cohesive fine-grained material which formed a hardened surface.

During each season, the eroded sediment from the south-facing, burned hillslope was coarser than the sediment from the north-facing, burned slope (fig. 4.6A). The relative coarseness of the eroded sediment from the burned south-facing hillslope compared with the north-facing, burned hillslopes and the unburned hillslopes may be a reflection of both the hillslope vegetation

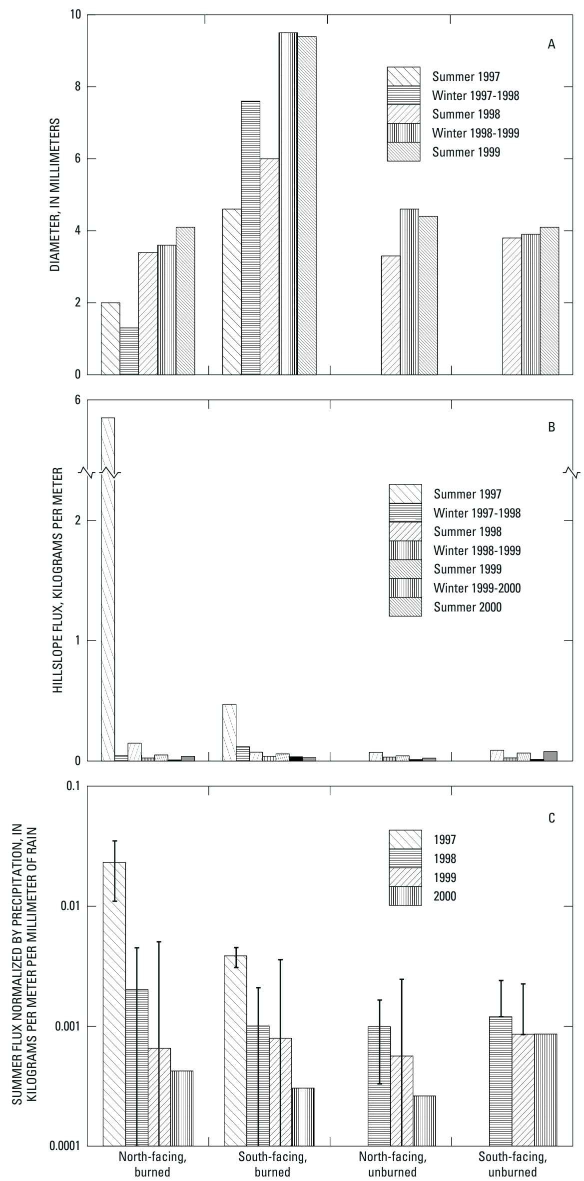


Figure 4.6. Seasonal change in median particle diameter and hillslope sediment flux in the Spring Creek watershed. A. Median particle diameter of eroded sediment collected in hillslope traps during summer (June-September, 122 days) and winter (October-May, 243 days) seasons. B. Hillslope flux for summer (June-September, 122 days) and winter (October-May, 243 days) seasons. Hillslope traps were not deployed in the unburned area until 1998. C. Sediment flux normalized by the amount of rain during the collection interval.

cover and the prior removal of some of the fine-grained sediment discussed above. On south-facing hillslopes, bunch grasses that existed before the wildfire have regrown. Even under unburned conditions, bare hillslopes are exposed between the bunch grasses. Field observations suggest that these spots without vegetation are more susceptible to dry ravel and disturbance than are the more vegetated hillslopes. The previous loss of the fine-grained material would reduce the soil cohesion and allow more coarse-grained material to erode. In contrast, the north-facing, burned hillslopes have developed a dense cover of herbaceous vegetation as they have recovered during the four years of our study. This vegetation cover on the recovering north-facing, burned hillslopes may be stabilizing the coarser-grained material.

Rills

Rills were found in the Spring Creek watershed on long hillslopes that had fewer obstructions than other slopes. Obstructions divert flow and provide frictional resistance; thus, a decrease in obstructions would decrease travel distance, and increase runoff velocity and shear stress. In general, south-facing hillslopes with lower tree density had more numerous and relatively larger rills than north-facing hillslopes. Hillslopes with rock outcrops or with a greater density of burnt trees and bushes had fewer rills because the length of the unobstructed surface was less and water running downhill was diverted many times by obstructions.

Rill Geometry

Rills in the Spring Creek watershed are hydraulic channels on planar or convex hillslopes. They were initially formed by unsteady flow during the 12 July 1996 rainstorm that probably lasted only a few hours. One major difference between these hydraulic channels and most streams and rivers, is the slope of the channel. These rills typically had channel slopes greater than 0.20, compared with 0.04 and 0.02 for the Spring Creek and Buffalo Creek channels, and with 0.00001 for the Mississippi River at the other end of the spectrum of hydraulic channels (table 4.8). These slopes are also greater than agriculture and rangeland rills. The top widths are similar to agricultural rills, but the shape differs. The shape of hydraulic channels can be described by the relation:

$$R = cA^b, \qquad \textbf{eq. 4. 1}$$

where R is the hydraulic radius, A is the cross-sectional area, and c and b are constants equal to 0.33 and 0.50 for a square channel. These constants depend on the width:depth ratio; for example, if a rectangular channel has a width:depth ratio of 0.20, then $c = 0.32$ and $b = 0.25$. But if the ratio is 20 (typical of many rivers), then $c = 0.02$ and $b = 0.96$. The mean cross-sectional area for rills on south- and north-facing hillslopes in the Spring Creek watershed was 0.017 m^2 and 0.022 m^2, respectively (table 4.9). The value of b for these rills was 0.55, slightly greater than the value for a square channel, but less than values for rivers (table 4.8).

Cross-sectional area of rills was weakly related to the distance, x, downhill. For north-facing rills the relation was

$$A = 0.0014x, \; r^2 = 0.25 \qquad \textbf{eq. 4. 2}$$

and for south-facing rills it was

$$A = 0.0080x, \; r^2 = 0.23 \qquad \textbf{eq. 4. 3}$$

The low correlation coefficient is caused by the large variability (fig. 4.7) resulting from increases in cross-sectional area as rills flow over roots that create wide plunge pools and as rills flow over bed rock that prevent incision. For example, when the measurements for Rill A51 and Rill 4 are connected in downstream order (fig. 4.7), an oscillatory pattern is created with the maximum area occurring just downstream from a root.

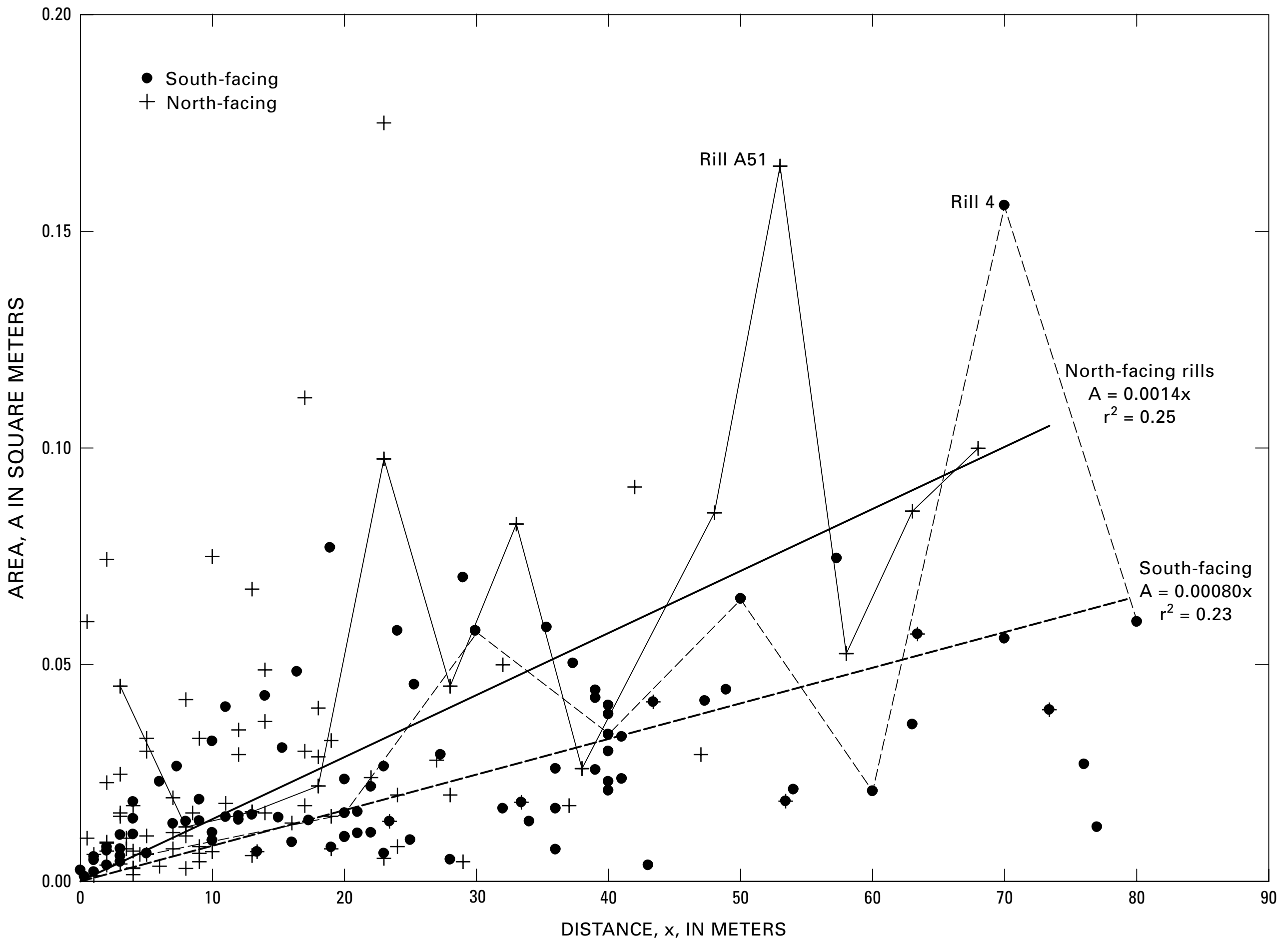


Figure 4.7. Cross-sectional area of rills in the Spring Creek watershed plotted as a function of distance from the beginning of the rills. Wide fluctuations, caused by roots and by shallow bedrock, are illustrated by connecting the measurements in Rill A51 by a lightweight solid line and those in Rill 4 by a short-dashed line. North-facing rills are shown by the plus symbols and south-facing rills are shown by solid circles.

Rill Evolution

Rills formed during the intense rainstorm on 12 July 1996. This conclusion is based on the examination of oblique photographs taken by the U. S. Forest Service (D. Bohon, oral commun., 1997) at the same location before and after the rainstorm. Monitoring of the rills started on 4 June 1998 and continued through 2000. The average change in minimum bed elevation with time was computed for three cross sections on Rill A (sections 1, 2, and 3), Rill B (sections 5, 6, and 7), and Rill C (sections 11, 12, and 13). The minimum bed elevation increased during the first year as the bottom of the rills filled with 0.006 to 0.013 m of sediment (fig. 4.8 and 4.9). On 17 July 1999 a relatively intense rainstorm (I_{30}=18 mm/h) localized near the rills, caused additional filling (0.003 m, from 0.013 to 0.016) in Rill A but caused incision in Rill B (0.032 m, from 0.012 down to -0.020) and in Rill C (0.030 m, from 0.006 down to -0.024). However, after the storm, all rills continued to fill. Rill B and Rill C filled more quickly than Rill A because sediment was deposited along the sides of the rills during the storm and was easily eroded during the months after the storm. An examination of some of the cross sections shown in figure 4.9 suggests that, in general, there was a corresponding lowering of the interrill area as rills filled.

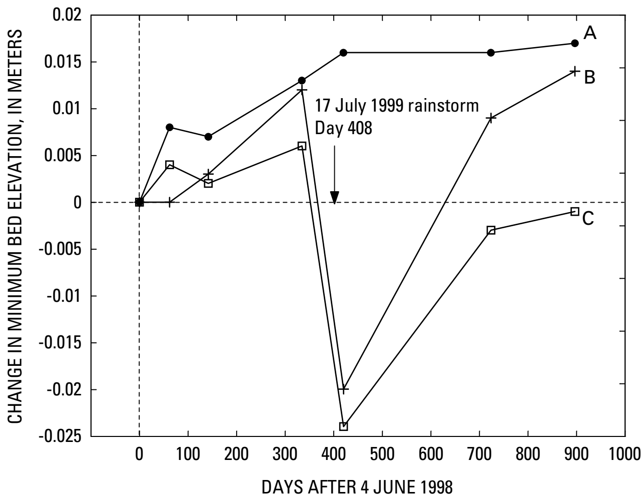


Figure 4.8. Change in minimum bed elevation of rills with time. Positive (negative) values represent aggradation (degradation) above (below) the minimum bed elevation for 4 June 1998. These values represent the average of three cross sections per rill.

Changes in rill widths and cross-sectional area with time were measured relative to an arbitrary reference elevation that was a fixed distance above the initial minimum bed elevation (4 June 1998) at each cross section. This reference elevation was 0.040 m, 0.050 m, and 0.063 m above the minimum bed elevation for Rills A, B, and C, respectively. Widths and area were normalized by dividing by the initial values on 4 June 1998 and the average was computed for the three middle sections of each rill (1, 2, 3 for rill A; 5, 6, 7 for rill B; 11, 12, 13 for rill C). At first, normalized widths increased slowly as the rills filled (fig. 4.10) by the processes of summer rainstorm erosion and winter freeze-thaw erosion of the side walls and deposition in the bottoms, where opportunistic plants like yellow evening-star (*Mentzelia speciosa L.*, Huckaby, oral commun., 1999) sprouted and helped trap sediment. During the first year (3 measurements excluding 4 June 1998), the rills widened but filled so that the annual-average normalized area for all three rills remained nearly constant (1.03, fig. 4.11). Each rill responded differently after the 17 July 1999 rainstorm, perhaps because of the different distances downhill from the beginning of the rill at which cross sections were measured. Rill A widened and filled, so the normalized area changed little after the storm but fluctuated around 1.0 until 2000. Rill B narrowed (because sediment was deposited along the sides of the rill), but it also deepened slightly so that the change in area was also small after the storm. Rill C widened but also deepened so that the change in area was the largest. After the 17 July storm, the area decreased as the rill bottom filled with sediment (fig. 4.9).

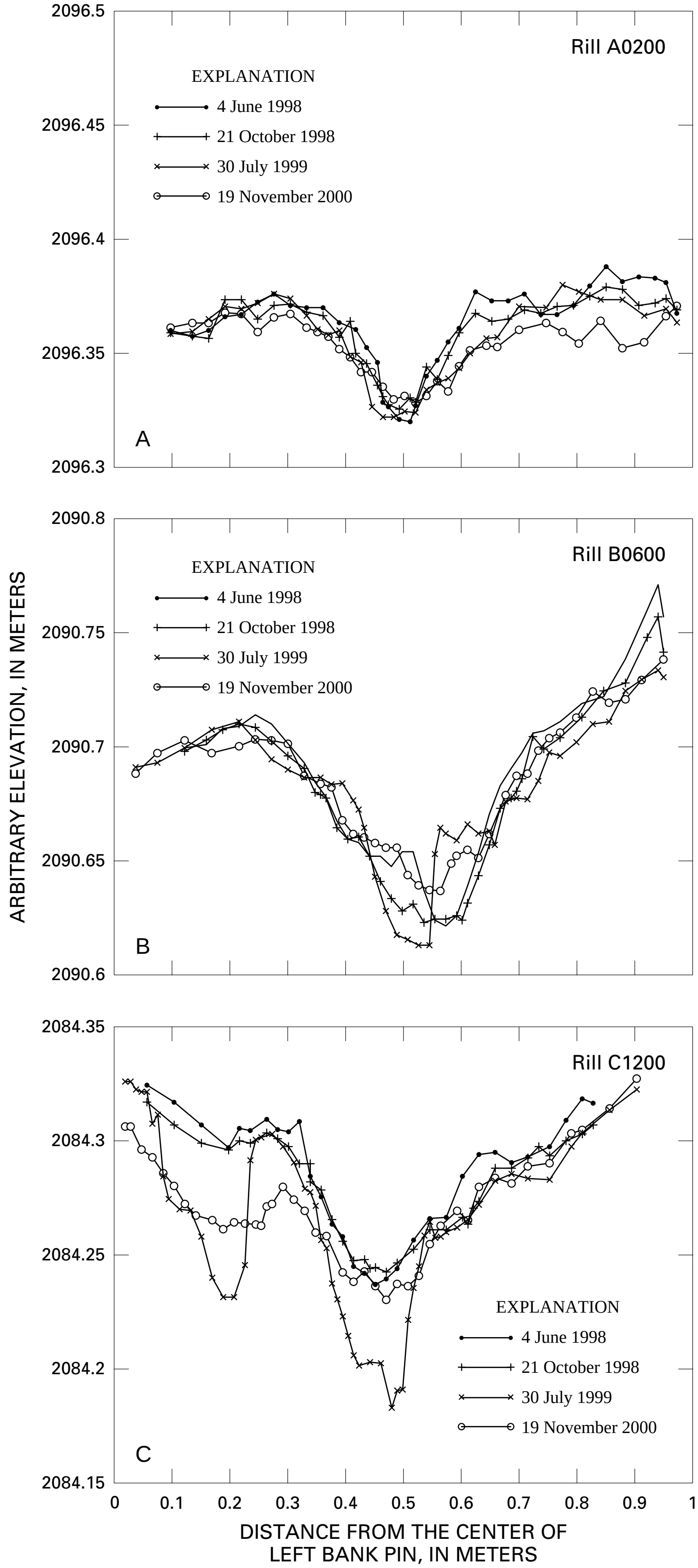


Figure 4.9. Change in rill profiles with time. A. Rill A, cross section 0200, B. Rill B, cross section 0600, and C. Rill C, cross section 1200. Left bank is determined by facing downslope.

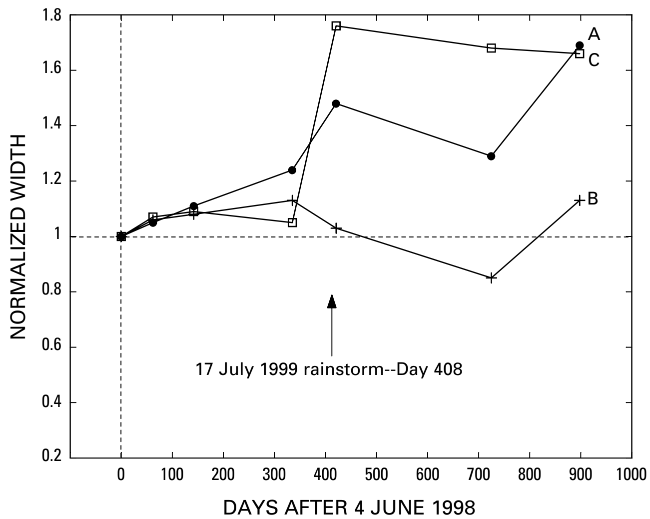


Figure 4.10. Change in normalized rill-width at a fixed elevation above the minimum bed elevation on 4 June 1998. These values are the average of three cross sections per rill.

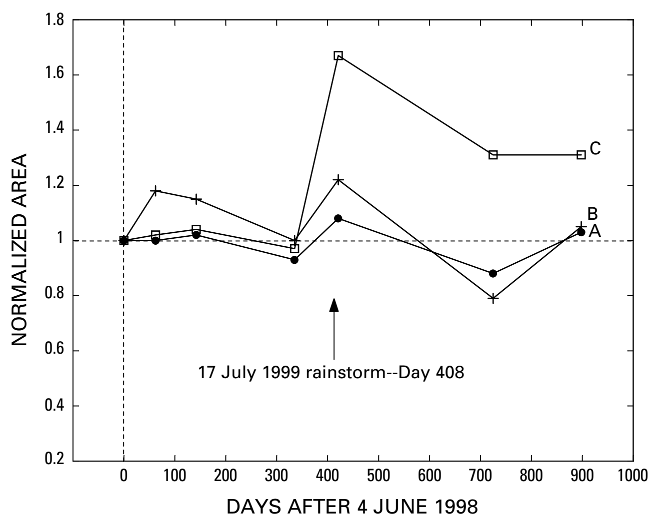


Figure 4.11. Change in normalized rill-area below a fixed elevation above the minimum bed elevation on 4 June 1998. These values are the average of three cross sections per rill.

Rill Erosion

Rill erosion during the first summer after the wildfire (1996) was estimated for north- and south-facing hillslopes. Mean rill length was estimated as the average length of overland flow (Horton, 1945) minus the length of the zone of no erosion starting at the hillslope ridge (about 5 m). Average rill length was about 20 m in W960 and 5 m in W1165; and the average rill cross-sectional area was 0.020 m^2 (n=681) for rills in several north- and south-facing watersheds (table

4.9). The number of rills that intersected a channel (some started and ended on a hillslope) in the two subwatersheds was similar (319 in W960 and 370 in W1165). Average rill spacing was about 10 m (some hillslopes in the watershed had no rills). Average rill top-width where the rill intersected a channel at the base of the hillslope was 0.36 m (this includes rills in watersheds other than W960 and W1165); thus, rills covered about 3.6 percent of the hillslope. Based on this information, the total volume of rill erosion was 100 m^3 in the south-facing watershed (W960) and 40 m^3 in the north-facing watershed (W1165).

No rill erosion was measured during 1997, and erosion rates for 1998, 1999, and 2000 are based on the three rill traps on a south-facing slope. Rill erosion rates increased rapidly when rain intensity exceeded about 30 mm/h. For example, the maximum sediment flux during the summer of 1998 was 0.36 kg/m when rainfall intensities were less than 29 mm/h. But the maximum sediment flux (22 kg/m) increased about 60-fold during the summer of 1999 when the rainfall intensity was 35 mm/h. Estimates of the average sediment flux to the stream channels during the summer are based on these time-averaged fluxes, channel length in the burned areas, and the rill density (3.6 percent). Estimated sediment yield to the stream channels by rill erosion was 310 m^3 in 1997 where we conservatively assumed the large rainstorm on 31 August 1997 produced rill erosion of the same order-of-magnitude as the rainstorm on 17 July 1999. Estimates of the average combined yields, to the channel of Buffalo and Spring Creeks, were 10 m^3, 310 m^3, and 10 m^3 in 1998, 1999, and 2000.

Table 4.1. Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

[mm, millimeter; kg, kilogram; L, liter; m^2, square meter; kg/m, kilogram per meter; kg/m/d, kilogram per meter per day; days in parenthesis are the number of days between collection dates; mm/h, millimeter per hour; of, overflow; ~, approximate; I_{30}, maximum 30-minute rainfall intensity; P, total rainfall; I_{30} and P calculated from data listed in U.S. Geological Survey 1997, 1998, 1999, and 2000; ±95%, 95-percent confidence limits; in 1997 the effective trap widths for traps 1, 2, 3, and 4, were 1.92, 2.07, 3.37, and 3.38 m, and in 1998-2000 the trap width was 1.00 m for all traps]

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
30 July 1997 (1 day; includes the storm on 29 July 1997; I_{30} = 13.25 mm/h; P = 7.1 mm)																		
1	32.7	10.0	22.7	6.2	6.3	7.1	7.9	11.7	16.7	9.8	1.6	0.0	0.185	0.4	9.9	6.90	0.096	0.096
2	32.3	8.7	23.6	8.0	5.8	5.4	7.2	9.5	16.3	13.3	2.3	0.0	0.138	0.4	13.1	7.86	0.067	0.067
3	26.0	6.2	19.8	4.9	6.1	7.2	9.3	14.7	18.3	12.3	1.1	0.0	0.346	0.8	16.8	14.98	0.10	0.10
4	13.2	4.1	9.1	4.3	2.7	4.4	8.3	13.0	23.0	24.2	6.9	0.0	0.146	2.4	7.5	14.52	0.043	0.043
Mean	26.0	7.2	18.8	5.8	5.2	6.0	8.2	12.2	18.6	14.9	3.0	0.0	0.204	1.0	11.8	--	0.076	0.076
±95%	14.0	4.2	10.4	2.7	2.6	2.0	1.5	3.7	4.8	10.4	4.2	0.0	0.150	1.4	6.7	--	0.041	0.041
8 August 1997 (9 days; I_{30} = 24.00 mm/h; P = 41.1 mm)																		
1	19.0	4.2	14.8	8.6	6.8	6.7	9.0	13.3	20.3	14.7	1.7	0.0	0.550	1.0	of	6.90	0.29	0.032
2	14.7	1.8	12.9	9.4	6.4	7.2	10.1	13.4	19.2	19.2	0.6	0.0	0.155	1.2	of	7.86	0.075	0.0083
3	10.7	--	--	5.3	6.2	7.3	10.0	16.9	24.4	17.5	1.6	0.0	1.623	1.6	of	14.98	0.48	0.054
4	7.1	1.3	5.8	2.9	3.8	5.3	8.0	14.8	25.2	28.0	5.0	0.0	0.350	2.6	of	14.52	0.10	0.012
Mean	12.9	--	--	6.6	5.8	6.6	9.3	14.6	22.3	19.8	2.2	0.0	0.670	1.6	--	--	0.24	0.026
±95%	8.6	--	--	4.7	2.2	1.4	1.5	2.6	4.3	9.6	3.2	0.0	1.057	1.2	--	--	0.29	0.033
14 August 1997 (6 days; I_{30} = 9.75 mm/h; P = 18.8 mm)																		
1	35.8	11.1	24.7	4.4	3.7	5.3	6.3	9.9	16.6	17.5	0.6	0.0	0.186	0.6	20.1	6.90	0.097	0.016
2	24.3	7.2	17.1	3.2	2.3	3.4	5.4	8.2	19.0	27.8	6.4	0.0	0.125	2.3	15.7	7.86	0.060	0.010
3	15.6	4.2	11.4	3.4	3.5	5.1	7.4	14.1	24.3	21.0	5.4	0.0	0.328	2.1	19.6	14.98	0.097	0.016
4	3.2	2.1	1.1	1.2	1.3	2.3	4.4	9.6	20.4	36.7	18.5	2.4	0.234	4.8	14.3	14.52	0.069	0.012
Mean	19.7	6.2	13.6	3.0	2.7	4.0	5.9	10.4	20.0	25.8	7.7	0.6	0.218	2.4	17.4	--	0.081	0.014
±95%	23.5	6.5	17.0	2.3	1.7	2.2	2.2	4.2	5.5	13.8	12.9	1.7	0.146	3.0	4.2	--	0.027	0.004
18 August 1997 (4 days; I_{30} = 3.00 mm/h; P = 4.8 mm)																		
1	7.4	--	--	2.3	1.4	3.7	8.4	16.7	21.4	19.5	19.1	0.0	0.021	3.0	0.9	6.90	0.011	0.0029
2	6.0	--	--	3.4	2.5	6.8	11.9	19.5	16.1	9.3	24.6	0.0	0.012	2.0	0.6	7.86	0.0058	0.0014
3	3.4	--	--	2.0	2.9	6.2	11.7	20.2	23.4	21.5	8.5	0.0	0.031	2.3	0.6	14.98	0.0092	0.0023
4	2.3	--	--	1.6	2.2	5.5	13.1	23.0	27.9	12.6	12.0	0.0	0.018	2.2	0.7	14.52	0.0053	0.0013
Mean	4.8			2.3	2.2	5.6	11.3	19.9	22.2	15.7	16.0	0.0	0.021	2.4	0.7	--	0.0078	0.0020
±95%	3.7			1.3	1.1	2.2	3.4	4.5	8.5	8.8	11.6	0.0	0.014	0.7	0.2	--	0.0041	0.0012
20 August 1997 (2 days; I_{30} = 5.00 mm/h; P = 2.8 mm)																		
1	3.3	--	--	2.6	2.6	5.3	9.9	19.7	28.3	22.4	5.9	0.0	0.015	2.5	1.2	6.90	0.0078	0.0039
2	5.6	--	--	4.7	3.2	5.6	9.5	15.9	32.5	23.0	0.0	0.0	0.013	2.3	0.7	7.86	0.0063	0.0031
3	1.5	--	--	2.0	3.0	7.0	12.1	25.6	35.7	13.1	0.0	0.0	0.020	2.0	0.4	14.98	0.0059	0.0030
4	5.8	--	--	1.9	1.5	4.4	9.7	17.5	26.7	32.5	0.0	0.0	0.021	2.7	0.9	14.52	0.0062	0.0031
Mean	4.0	--	--	2.8	2.6	5.6	10.3	19.7	30.8	22.8	1.5	0.0	0.017	2.4	0.8	--	0.0066	0.0033
±95%	3.1	--	--	2.0	1.2	1.9	1.9	7.0	6.5	14.0	4.2	0.0	0.006	0.5	0.6	--	0.0014	0.00065

Table 4.1. (Continued) Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
31 August 1997 (11 days; I_{30} = 11.25 mm/h; 13.7 mm)																		
1	39.4	12.1	27.3	4.5	4.6	5.7	6.9	10.2	14.1	14.1	0.4	0.0	0.199	0.3	17.8	6.90	0.10	0.0094
2	36.9	18.4	18.5	5.2	3.2	5.1	8.0	10.8	16.1	12.0	2.7	0.0	0.078	0.5	13.4	7.86	0.038	0.0034
3	8.0	--	--	5.0	5.9	7.5	11.0	20.1	26.9	15.2	0.3	0.0	0.291	1.6	of	14.98	0.086	0.0078
4	15.8	--	--	2.5	2.6	4.8	9.4	14.8	20.5	23.0	6.6	0.0	0.128	2.0	11.9	14.52	0.036	0.0033
Mean	25.0	--	--	4.3	4.1	5.8	8.8	14.0	19.4	16.1	2.5	0.0	0.172	1.1	--	--	0.065	0.0060
±95%	22.6	--	--	1.9	2.4	1.9	3.0	7.1	9.2	7.9	4.5	0.0	0.153	1.2	--	--	0.046	0.0043
4 September 1997 (traps overflowed; totals are minimum estimates; duration was rounded to 1 day; I_{30} = 88.00 mm/h; P = 51.3 mm)																		
1	6.8	--	--	3.6	4.0	5.8	7.8	13.8	22.4	24.3	10.2	1.3	>5.865	2.7	of	6.90	>3.0	>3.0
2	4.6	--	--	2.6	3.1	4.8	7.0	12.9	21.4	25.8	14.2	3.6	>9.288	3.4	of	7.86	>4.5	>4.5
3	3.6	--	--	2.6	3.8	5.2	7.2	13.3	23.4	27.7	12.2	0.7[a]	>14.889	3.2	of	14.98	>4.4	>4.4
4	2.6	--	--	1.5	2.0	3.7	6.2	12.4	23.2	29.8	16.1	2.5	>3.969	3.9	of	14.52	>1.2	>1.2
Mean	4.4	--	--	2.6	3.2	4.9	7.0	13.1	22.6	26.9	13.2	2.0	--	3.3	--	--	>3.3	>3.3
±95%	3.0	--	--	1.5	1.4	1.5	1.2	1.0	1.4	4.0	4.2	2.1	--	0.9	--	--	NA	NA
15 September 1997 (11 days; I_{30} = 13.75 mm/h; P = 8.4 mm)																		
1	16.1	--	--	7.5	7.7	9.3	11.8	15.4	17.8	11.5	2.9	0.0	0.602	0.9	of	6.90	0.31	0.028
2	20.3	4.9	15.4	5.2	6.1	8.5	12.1	16.5	20.8	8.2	2.1	0.0	0.596	0.9	16.6	7.86	0.29	0.026
3	19.6	--	--	1.8	6.1	7.0	8.2	14.2	22.6	16.3	4.2	0.0	0.389	1.5	of	14.98	0.12	0.010
4	5.7	0.8	4.9	2.0	2.4	3.5	7.0	12.6	24.7	30.7	11.6	0.0	0.204	3.4	7.4	14.52	0.060	0.0055
Mean	15.4	--	--	4.1	5.6	7.1	9.8	14.7	21.5	16.7	5.2	0.0	0.448	1.7		--	0.20	0.017
±95%	10.5	--	--	4.1	3.8	4.2	3.7	2.8	5.0	16.2	6.8	0.0	0.287	1.8		--	0.18	0.016
2 October 1997 (17 days; I_{30} = 5.00 mm /h; P =7.9 mm)																		
1	31.9	--	--	3.9	5.3	8.7	9.7	10.1	6.3	7.7	16.4	0.0	0.021	0.5	6.0	6.90	0.011	0.00064
2	17.7	--	--	2.8	5.7	11.4	17.7	19.2	17.7	7.8	0.0	0.0	0.014	0.9	2.4	7.86	0.0068	0.00040
3	22.4	--	--	3.5	2.1	6.3	11.2	14.7	21.7	7.7	10.5	0.0	0.014	1.3	~2.8	14.98	0.0042	0.00024
4	23.2	--	--	0.9	2.8	6.5	12.0	13.9	15.7	15.7	9.3	0.0	0.011	1.3	~3.0	14.52	0.0032	0.00019
Mean	23.8	--	--	2.7	4.0	8.2	12.6	14.5	15.4	9.7	9.0	0.0	0.015	1.0	~4	--	0.0063	0.00037
±95%	10.2	--	--	2.2	2.6	3.7	5.8	6.6	11.1	5.8	11.8	0.0	0.007	0.6	~3	--	0.0056	0.00033
16 June 1998 (11 days; I_{30} = 13.75 mm/h; P = 14.7 mm)																		
1	0.3	--	--	0.9	1.6	3.1	6.4	10.0	13.5	64.2	0.0	0.0	0.030	4.9	2.0	5.0	0.030	0.0027
2	1.6	--	--	2.3	3.0	5.5	12.7	22.1	37.2	15.6	0.0	0.0	0.021	2.2	1.7	5.0	0.021	0.0019
3	0.4	--	--	0.9	1.6	2.9	6.3	11.9	27.5	48.6	0.0	0.0	0.059	3.9	1.6	5.0	0.059	0.0054
4	0.2	--	--	0.4	0.8	1.6	3.6	6.8	17.5	68.9	0.0	0.0	0.104	5.1	2.1	5.0	0.10	0.0094
Mean	0.6	--	--	1.1	1.8	3.3	7.2	12.7	23.9	49.3	0.0	0.0	0.054	4.0	1.8	--	0.052	0.0048
±95%	1.0	--	--	1.4	1.6	2.9	6.6	11.0	17.1	38.4	0.0	0.0	0.060	2.2	0.4	--	0.058	0.0054

Table 4.1. (Continued) Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
11 July 1998 (25 days; I_{30} = 7.50 mm/h[b]; P = 21.1 mm)																		
1	1.2	--	--	2.4	3.7	6.1	9.8	9.8	6.1	3.7	57.3	0.0	0.008	9.0	2.0	5.0	0.008	0.00032
2	3.2	--	--	3.2	3.2	11.6	19.0	25.3	24.2	10.5	0.0	0.0	0.010	1.4	1.9	5.0	0.010	0.00040
3	1.3	--	--	2.5	4.4	7.0	12.7	21.5	22.2	12.0	16.5	0.0	0.016	2.0	1.8	5.0	0.016	0.00064
4	0.9	--	--	0.9	1.4	5.1	6.5	11.2	18.6	25.6	29.8	0.0	0.022	4.8	2.5	5.0	0.022	0.00088
Mean	1.6	--	--	2.2	3.2	7.4	12.0	17.0	17.8	13.0	25.9	0.0	0.014	4.3	2.0	--	0.014	0.00056
±95%	1.7	--	--	1.7	2.2	4.7	9.0	11.2	13.0	15.8	41.3	0.0	0.010	5.5	0.5	--	0.010	0.00040
4 August 1998 (24 days; I_{30} = 28.50 mm/h ; P = 69.1 mm)																		
1	4.8	0.1	4.7	3.5	4.5	9.6	15.3	17.8	23.1	21.4	0.0	0.0	0.040	1.7	9.2	5.0	0.040	0.0017
2	4.4	0.1	4.3	2.8	4.6	8.6	12.7	20.0	32.1	14.9	0.0	0.0	0.054	1.8	4.1	5.0	0.054	0.0022
3	3.3	0.1	3.2	2.9	2.4	5.3	8.9	15.7	21.6	20.3	8.8	10.9	0.119	3.1	4.2	5.0	0.12	0.0050
4	0.8	--	--	0.8	1.9	4.3	7.0	14.2	26.9	33.3	10.9	0.0	0.119	3.6	8.2	5.0	0.12	0.0050
Mean	3.3	--	--	2.5	3.4	7.0	11.0	16.9	25.9	22.5	4.9	2.7	0.083	2.6	6.4	--	0.084	0.0035
±95%	2.9	--	--	1.9	1.9	3.8	6.0	4.2	7.6	13.2	7.8	7.8	0.057	1.4	3.7	--	0.058	0.0024
9 September 1998 (36 days; I_{30} = 14.75 mm /h; P = 36.1 mm)																		
1	4.4	--	--	0.6	1.8	5.3	8.6	15.2	20.7	28.4	15.1	0.0	0.018	3.4	5.1	5.0	0.018	0.00050
2	2.7	--	--	2.4	4.9	9.7	14.6	23.6	35.6	6.5	0.0	0.0	0.019	1.7	3.1	5.0	0.019	0.00053
3	4.9	--	--	0.4	1.9	5.9	9.6	16.1	24.0	29.6	7.8	0.0	0.043	2.9	3.7	5.0	0.043	0.0012
4	0.5	--	--	0.5	1.4	3.4	9.2	8.7	27.9	31.6	16.8	0.0	0.056	3.9	4.3	5.0	0.056	0.0016
Mean	3.1	--	--	1.0	2.5	6.1	10.5	15.9	27.0	24.0	9.9	0.0	0.034	3.0	4.0	--	0.034	0.00096
±95%	3.2	--	--	1.4	2.5	4.5	4.3	10.7	10.7	18.1	12.1	0.0	0.027	1.6	1.4	--	0.027	0.00079
26 May 1999 (259 days; rain gage was not maintained during part of collection interval)																		
1	7.8	--	--	6.8	3.8	11.5	14.8	14.8	10.7	17.2	12.5	0.0	0.017	1.4	c	5.0	0.017	0.000066
2	5.8	--	--	6.9	3.1	10.8	16.8	28.0	28.7	0.0	0.0	0.0	0.020	1.2	c	5.0	0.020	0.000077
3	1.4	--	--	0.8	1.8	3.2	5.7	10.4	14.3	23.6	38.9	0.0	0.055	6.1	c	5.0	0.055	0.00021
4	1.0	--	--	0.5	1.1	2.1	3.9	8.4	18.4	35.3	19.9	9.5	0.140	5.7	c	5.0	0.140	0.00054
Mean	4.0	--	--	3.8	2.4	6.9	10.3	15.4	18.0	19.0	17.8	2.4	0.058	3.6	--	--	0.058	0.00022
±95%	4.9	--	--	4.6	1.9	6.8	9.3	14.1	13.0	25.4	28.0	6.8	0.089	3.5	--	--	0.089	0.00034
21 July 1999 (56 days; I_{30} = 18.75 mm/h; P = 53.6 mm)																		
1	1.3	--	--	1.6	0.7	3.3	5.5	10.4	15.2	27.4	34.6	0.0	0.024	5.8	3.0	5.0	0.024	0.00043
2	1.5	--	--	0.9	1.8	3.6	7.3	18.5	33.4	16.3	16.7	0.0	0.034	3.0	3.8	5.0	0.034	0.00061
3	1.2	--	--	2.6	1.3	5.2	7.7	14.0	26.7	36.9	4.4	0.0	0.052	3.3	6.9	5.0	0.052	0.00093
4	0.3	--	--	0.3	0.8	1.8	4.0	9.6	24.2	37.6	16.4	5.2	0.179	5.0	5.1	5.0	0.18	0.0032
Mean	1.1	--	--	1.4	1.2	3.5	6.1	13.1	24.9	29.6	18.0	1.3	0.072	4.3	4.7	--	0.072	0.0013
±95%	0.9	--	--	1.7	0.8	2.5	2.7	6.4	13.1	15.4	21.7	3.7	0.112	2.0	2.8	--	0.11	0.0020

Table 4.1. (Continued) Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
3 November 1999 (105 days; rain gage was not maintained during part of collection interval)																		
1	1.0	--	--	1.2	3.2	7.6	11.8	17.2	32.1	25.8	0.0	0.0	0.005	2.5	--	5.0	0.0050	0.000048
2	0.7	--	--	0.9	0.5	4.6	11.1	25.4	34.5	22.4	0.0	0.0	0.014	2.4	--	5.0	0.014	0.00013
3	0.4	--	--	0.6	1.5	2.6	4.6	9.7	18.7	28.7	33.1	0.0	0.070	5.7	--	5.0	0.070	0.00067
4	0.5	--	--	0.3	0.6	1.5	3.6	9.1	14.9	69.4	0.0	0.0	0.091	5.1	--	5.0	0.091	0.00087
Mean	0.6	--	--	0.8	1.4	4.1	7.8	15.4	25.0	36.6	8.3	0.0	0.045	3.9	--	--	0.045	0.00043
±95%	0.4	--	--	0.6	1.9	4.4	5.9	11.7	14.1	33.8	23.8	0.0	0.062	2.4	--	--	0.062	0.00059
23 May 2000 (202 days; rain gage was not maintained during part of collection interval)																		
1													0.002	--	--	5.0	0.002	0.0000099
2													0.004	--	--	5.0	0.004	0.000020
3	No Size Analysis												0.010	--	--	5.0	0.010	0.000050
4													0.040	--	--	5.0	0.040	0.00020
Mean													0.014	--	--	--	0.014	0.000070
±95%													0.027	--	--	--	0.027	0.00014
19 November 2000 (180 days; rain gage was not maintained during part of collection interval)																		
1													0.0049	--	--	5.0	0.0049	0.000027
2													0.062	--	--	5.0	0.062	0.00034
3	No Size Analysis												0.160	--	--	5.0	0.16	0.00089
4													0.231	--	--	5.0	0.23	0.0013
Mean													0.114	--	--	--	0.11	0.00064
±95%													0.163	--	--	--	0.16	0.00092

[a]0.3 percent was in the greater than 32 mm size class.

[b]A rain gage malfunctioned during the collection interval and this is the maximum I_{30} for the available data.

[c]No runoff volumes were collected because this was the start of the rainfall sampling season and only the sediment from the winter season was collected.

Table 4.2. Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

[mm, millimeter; kg, kilogram; L, liter; m^2, square meter; kg/m, kilogram per meter; kg/m/d, kilogram per meter per day; days in parenthesis are the number of days between collection dates; mm/h, millimeter per hour; of, overflow; ~, approximate; I_{30}, maximum 30-minute rainfall intensity; P, total rainfall; I_{30} and P calculated from data listed in U.S. Geological Survey 1997, 1998, 1999, and 2000; ±95%, 95-percent confidence limits; in 1997 the effective trap widths for traps 5, 6, 7, and 8, were 1.81, 2.35, 2.51, and 2.40 m, and in 1998-2000 the trap width was 1.00 m for all traps]

Trap	Percent of sample total: Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux (kg/m)	Flux Rate (kg/m/d)
29 July 1997 (8 days; includes the storm on 29 July 1997; I_{30} = 13.75 mm/h ; P = 24.4 mm)																		
5	8.4	2.7	5.7	2.0	1.3	2.2	3.8	7.7	19.0	36.4	14.9	4.2	0.151	4.6	19.5	4.89	0.083	0.010
6	11.9	--	--	1.6	4.6	9.3	38.7	3.1	23.2	7.7	0.0	0.0	0.013	0.79	2.9	8.02	0.0055	0.00069
7	8.8	3.2	5.6	1.0	1.3	1.8	2.9	7.8	24.8	43.8	7.8	0.0	0.140	4.1	8.4	9.29	0.056	0.0070
8	16.9	4.7	12.2	3.7	2.5	5.0	8.1	14.1	23.7	19.9	6.0	0.0	0.048	2.0	5.2	13.22	0.020	0.0025
Mean	11.5	3.6	7.8	2.1	2.4	4.6	13.4	8.2	22.7	27.0	7.2	1.0	0.088	2.9	9.0	--	0.041	0.0051
±95%	6.1	2.6	8.6	1.9	2.4	5.4	25.8	7.9	4.2	26.0	10.7	3.0	0.099	2.7	12.0	--	0.056	0.0070
8 August 1997 (10 days; I_{30} =24.00 mm/h; P = 41.1 mm)																		
5	10.6	5.0	5.6	3.1	2.1	3.7	6.0	11.6	23.2	33.5	6.4	0.0	0.090	3.1	13.2	4.89	0.050	0.0050
6	15.5	--	--	3.4	6.0	12.9	23.3	24.1	11.2	3.4	0.0	0.0	0.012	0.76	5.2	8.02	0.0051	0.00051
7	9.4	3.3	6.1	1.0	1.3	1.8	2.6	5.0	13.0	40.0	26.1	0.0	0.125	5.6	7.8	9.29	0.050	0.0050
8	22.8	7.0	15.8	2.7	5.0	7.3	10.8	14.3	16.2	15.4	5.4	0.0	0.026	1.1	5.5	13.22	0.011	0.0011
Mean	14.6	5.1	9.2	2.6	3.6	6.4	10.7	13.8	15.9	23.1	9.5	0.0	0.063	2.6	7.9	--	0.029	0.0029
±95%	9.6	4.8	13.3	1.7	3.4	8.0	14.9	13.8	8.6	26.4	18.8	0.0	0.081	3.5	5.8	--	0.032	0.0032
14 August 1997 (6 days; I_{30} = 9.75 mm/h; P = 18.8 mm)																		
5	3.5	--	--	0.5	0.8	1.3	1.8	3.4	9.2	24.3	10.0	45.1	0.100	12.2	10.8	4.89	0.055	0.0092
6	3.7	--	--	1.2	1.2	3.7	8.6	18.5	18.5	32.1	12.4	0.0	0.008	3.4	2.1	8.02	0.0034	0.00057
7	1.8	--	--	0.3	0.3	1.0	2.1	4.2	11.7	44.7	34.0	0.0	0.038	6.6	2.0	9.29	0.015	0.0025
8	9.5	--	--	1.4	1.4	2.7	4.5	8.6	19.8	28.8	23.4	0.0	0.022	4.3	3.8	13.22	0.0092	0.0015
Mean	4.6	--	--	0.8	0.9	2.2	4.2	8.7	14.8	32.5	20.0	11.3	0.042	6.6	4.7	--	0.021	0.0034
±95%	5.5	--	--	0.8	0.8	1.9	4.9	10.9	7.6	14.7	17.3	32.5	0.066	6.3	6.3	--	0.037	0.0062
18 August 1997 (4 days; I_{30} = 3.00 mm/h; P = 4.8 mm)																		
5	3.5	--	--	0.9	0.9	1.8	3.5	8.8	16.8	45.6	18.1	0.0	0.023	5.2	2.4	4.89	0.013	0.0032
6	4.2	--	--	3.8	3.8	7.7	19.2	26.9	19.2	15.4	0.0	0.0	0.003	1.4	0.6	8.02	0.0013	0.00032
7	1.5	--	--	0.8	0.8	1.5	3.0	5.3	12.0	26.3	48.9	0.0	0.013	7.8	0.5	9.29	0.0052	0.0013
8	2.5	--	--	2.1	2.1	4.2	8.3	18.7	14.5	47.7	0.0	0.0	0.005	3.6	0.6	13.22	0.0021	0.00052
Mean	2.9	--	--	1.9	1.9	3.8	8.5	14.9	15.6	33.8	16.8	0.0	0.011	4.5	1.0	--	0.0054	0.0013
±95%	1.9	--	--	2.2	2.2	4.5	11.7	15.6	5.2	23.3	35.2	0.0	0.014	4.6	1.4	--	0.0084	0.0021
20 August 1997 (2 days; I_{30} = 5.00 mm/h; P = 2.8 mm)																		
5	4.6	--	--	1.6	0.8	2.3	3.1	6.2	15.5	39.5	26.4	0.0	0.013	5.6	1.4	4.89	0.0072	0.0036
6	8.3	--	--	8.3	8.3	12.5	25.0	25.0	12.5	0.0	0.0	0.0	0.001	0.75	0.3	8.02	0.00043	0.00021
7	1.7	--	--	3.2	1.7	3.2	6.4	6.4	35.5	41.9	0.0	0.0	0.003	3.5	0.2	9.29	0.0012	0.00060
8	6.2	--	--	6.2	12.5	12.5	12.5	31.2	18.8	0.0	0.0	0.0	0.002	1.0	0.3	13.22	0.00083	0.00042
Mean	5.2	--	--	4.8	5.8	7.6	11.8	17.2	20.6	20.4	6.6	0.0	0.005	2.7	0.6	--	0.0024	0.0012
±95%	4.8	--	--	4.8	8.4	7.3	15.8	18.0	16.6	30.2	19.0	0.0	0.009	3.5	0.9	--	0.0049	0.0024

Table 4.2. (Continued) Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
31 August 1997 (11 days; I_{30} = 11.25 mm/h; P = 13.7 mm)																		
5	5.8	--	--	1.2	1.9	2.9	4.2	8.7	20.5	42.7	12.2	0.0	0.052	4.4	6.1	4.89	0.029	0.0026
6	11.9	--	--	4.5	1.5	7.5	14.9	20.9	16.4	22.4	0.0	0.0	0.007	1.5	1.7	8.02	0.0030	0.00027
7	8.0	--	--	0.9	1.8	2.2	4.5	8.0	21.9	41.5	11.2	0.0	0.022	4.3	2.2	9.29	0.0088	0.00080
8	17.4	--	--	2.9	2.0	3.1	3.4	7.4	11.1	10.0	5.1	37.4	0.035	5.1	6.4	13.22	0.015	0.0013
Mean	10.8	--	--	2.4	1.8	3.9	6.8	11.2	17.5	29.2	7.1	9.4	0.029	3.8	4.1	--	0.014	0.0012
±95%	8.4	--	--	2.6	0.4	3.8	8.3	9.7	7.8	23.5	8.8	26.9	0.032	2.6	3.4	--	0.019	0.0017
4 September 1997 (traps overflowed; totals are minimum estimates; duration was rounded to 1 day; I_{30} = 88.00 mm/h; P = 51.3 mm)																		
5	0.3	--	--	0.5	0.6	1.0	1.5	2.9	10.8	34.5	42.6	5.3	0.272	7.8	of	4.89	0.15	0.15
6	0.4	--	--	0.4	0.4	0.6	1.0	2.5	6.8	36.4	51.6	0.0	0.254	8.2	of	8.02	0.11	0.11
7	3.5	--	--	2.8	2.3	2.4	3.2	7.5	21.1	34.0	21.5	1.7	1.820	4.8	of	9.29	0.73	0.73
8	2.4	--	--	1.5	1.7	2.7	4.8	11.2	25.7	36.6	12.6	0.8	3.403	4.0	of	13.22	1.42	1.42
Mean	1.6	--	--	1.3	1.2	1.7	2.6	6.0	16.1	35.4	32.1	2.0	1.437	6.2	--	--	0.60	0.60
±95%	2.3	--	--	1.7	1.4	1.5	2.7	6.3	13.6	1.9	28.1	3.8	2.267	3.0	--	--	0.94	0.94
15 September 1997 (11 days; I_{30} = 13.75 mm/h; P = 8.4 mm)																		
5	0.8	--	--	1.2	1.0	2.3	3.4	5.4	13.1	30.5	32.6	9.7	0.128	7.0	4.0	4.89	0.071	0.0064
6	1.2	--	--	0.4	0.8	1.9	5.8	12.4	18.2	32.6	26.7	0.0	0.026	5.1	1.0	8.02	0.011	0.0010
7	7.4	--	--	0.7	0.6	5.8	9.3	18.1	24.2	24.3	9.6	0.0	0.166	2.7	4.0	9.29	0.066	0.0060
8	4.1	0.3	3.8	2.7	2.5	4.9	6.9	12.2	23.9	33.3	9.6	0.0	0.101	3.4	4.0	13.22	0.042	0.0038
Mean	3.4	--	--	1.2	1.2	3.7	6.4	12.0	19.8	30.2	19.6	2.4	0.105	4.6	3.2	--	0.048	0.0043
±95%	4.8	--	--	1.7	1.4	2.8	4.2	9.1	8.0	6.5	16.6	7.0	0.101	3.1	2.2	--	0.043	0.0040
2 October 1997 (17 days; I_{30} = 5.00 mm/h; P = 7.9 mm)																		
5	2.1	--	--	0.2	0.3	0.6	1.4	2.4	5.7	25.2	36.6	25.5	0.066	10.6	3.9	4.89	0.036	0.0021
6	14.4	--	--	1.5	0.0	1.5	1.5	3.1	1.5	9.2	67.3	0.0	0.007	10.0	0.8	8.02	0.0026	0.00015
7	0.4	--	--	0.9	0.2	1.8	2.9	7.0	17.2	26.9	13.2	29.5	0.079	6.9	~1.6	9.29	0.031	0.0018
8	8.0	--	--	0.0	2.0	6.0	8.0	14.0	36.0	26.0	0.0	0.0	0.005	2.7	~1.4	13.22	0.0021	0.00012
Mean	6.2	--	--	0.6	0.6	2.5	3.4	6.6	15.1	21.8	29.3	13.8	0.039	7.6	~2	--	0.018	0.0010
±95%	10.1	--	--	1.1	1.4	3.9	4.8	8.4	24.8	12.7	48.5	21.2	0.053	5.7	~2	--	0.024	0.0014
16 June 1998 (11 days; I_{30} = 13.75 mm/h; P = 14.7 mm)																		
5	0.1	--	--	0.2	0.6	1.2	2.3	2.6	5.8	87.3	0.0	0.0	0.050	5.7	1.7	5.0	0.050	0.0045
6	1.1	--	--	2.8	4.4	11.1	15.8	11.4	10.0	43.3	0.0	0.0	0.004	2.7	1.4	5.0	0.0040	0.00036
7	0.2	--	--	0.7	1.4	2.9	5.3	12.7	29.3	47.5	0.0	0.0	0.022	3.8	1.4	5.0	0.022	0.0020
8	1.3	--	--	2.0	3.6	6.5	10.4	12.2	18.6	45.3	0.0	0.0	0.008	3.5	1.4	5.0	0.0080	0.00073
Mean	0.7	--	--	1.4	2.5	5.4	8.4	9.7	15.9	55.8	0.0	0.0	0.021	3.9	1.5	--	0.021	0.0019
±95%	0.9	--	--	1.9	2.7	7.1	9.7	7.3	16.9	31.7	0.0	0.0	0.033	2.2	0.2	--	0.033	0.0030

Table 4.2. (Continued) Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
11 July 1998 (25 days; I_{30} = 7.50 mm/h[a]; P = 21.1 mm)																		
5	1.5	--	--	2.0	5.1	10.2	10.2	10.2	20.3	40.6	0.0	0.0	0.002	3.1	1.4	5.0	0.0020	0.000080
6	2.6	--	--	1.9	6.4	6.4	6.4	6.4	0.0	70.1	0.0	0.0	0.002	5.1	2.0	5.0	0.0020	0.000080
7	0.9	--	--	0.9	1.9	3.7	10.3	7.5	15.9	48.6	10.3	0.0	0.011	4.7	2.1	5.0	0.011	0.00044
8	0.0	--	--	1.0	3.2	9.6	12.8	9.6	25.6	38.3	0.0	0.0	0.003	3.1	2.1	5.0	0.0030	0.00012
Mean	1.2	--	--	1.4	4.2	7.5	9.9	8.4	15.4	49.4	2.6	0.0	0.004	4.0	1.9	--	0.0045	0.00018
±95%	1.9	--	--	0.8	3.2	4.7	4.6	2.7	18.4	22.9	7.4	0.0	0.006	1.5	0.5	--	0.0065	0.00026
4 August 1998 (24 days; I_{30} = 28.50 mm/h P = 69.1 mm)																		
5	0.1	--	--	0.1	0.3	1.0	1.7	2.6	6.4	32.7	31.7	23.4	0.070	9.3	3.9	5.0	0.070	0.0029
6	0.1	--	--	0.2	1.4	2.8	3.5	4.2	6.3	25.1	56.5	0.0	0.014	8.9	6.3	5.0	0.014	0.00058
7	0.4	--	--	0.5	0.5	1.4	3.0	8.3	20.4	28.3	13.3	23.9	0.080	6.2	6.5	5.0	0.080	0.0033
8	0.9	--	--	0.9	2.7	5.0	6.8	8.6	17.3	32.3	25.4	0.0	0.022	5.0	6.5	5.0	0.022	0.00092
Mean	0.4	--	--	0.4	1.2	2.6	3.8	5.9	12.6	29.6	31.7	11.8	0.046	7.4	5.8	--	0.046	0.0019
±95%	0.6	--	--	0.6	1.7	2.9	3.7	4.3	10.2	5.2	31.1	17.2	0.048	3.1	1.9	--	0.048	0.0020
9 September 1998 (36 days; I_{30} = 14.75 mm/h; P = 36.1 mm)																		
5	0.4	--	--	0.0	0.2	0.9	1.6	1.9	4.7	27.4	29.0	33.9	0.054	11.6	4.0	5.0	0.054	0.0015
6	0.0	--	--	0.3	0.8	1.8	2.7	3.1	4.3	8.8	78.1	0.0	0.010	10.9	2.4	5.0	0.010	0.00028
7	0.2	--	--	0.5	0.4	1.1	2.0	4.8	14.9	27.0	30.0	19.2	0.074	7.9	3.2	5.0	0.074	0.0021
8	1.0	--	--	1.5	3.0	4.8	5.6	9.7	15.6	39.1	19.7	0.0	0.010	4.9	2.0	5.0	0.010	0.00028
Mean	0.4	--	--	0.6	1.1	2.2	3.0	4.9	9.9	25.6	39.2	13.3	0.037	8.8	2.9	--	0.037	0.0010
±95%	0.7	--	--	1.6	2.0	2.8	2.9	5.6	8.1	21.8	42.0	24.4	0.046	4.8	1.4	--	0.046	0.0013
16 November 1998 (68 days; rain gage was not maintained during part of collection interval)																		
5	0.2	--	--	0.2	0.2	0.9	1.4	2.9	3.2	26.8	64.2	0.0	0.018	9.8	1.8	5.0	0.018	0.00026
6	1.7	--	--	0.3	1.0	1.5	1.1	2.2	2.8	4.8	84.6	0.0	0.007	11.3	3.2	5.0	0.0070	0.00010
7	0.2	--	--	0.1	0.2	0.6	1.8	6.2	24.2	12.2	54.4	0.0	0.013	8.7	3.7	5.0	0.013	0.00019
8	0.0	--	--	0.2	0.0	0.3	0.3	1.4	3.2	9.4	85.2	0.0	0.007	11.3	3.0	5.0	0.0070	0.00010
Mean	0.5	--	--	0.2	0.4	0.8	1.2	3.2	8.4	13.3	72.1	0.0	0.011	10.3	2.9	--	0.011	0.00016
±95%	1.2	--	--	0.1	0.7	0.9	1.1	3.5	15.4	15.8	22.2	0.0	0.008	1.9	1.4	--	0.0080	0.00012
5 May 1999 (170 days; rain gage was not maintained during part of collection interval)																		
5	0.1	--	--	0.1	0.1	0.2	0.3	0.6	0.9	3.9	41.0	52.8	0.136	16.8	12.9	5.0	0.14	0.00080
6	0.4	--	--	0.5	0.3	1.2	1.6	2.5	4.3	22.7	66.4	0.0	0.036	10.0	22.3	5.0	0.036	0.00021
7	0.2	--	--	0.3	0.1	0.7	1.3	3.6	11.4	25.4	51.7	5.3	0.122	9.1	~24	5.0	0.12	0.00072
8	0.6	--	--	0.2	0.6	1.2	1.8	3.0	3.7	16.6	42.2	30.0	0.021	12.2	4.0	5.0	0.021	0.00012
Mean	0.3	--	--	0.3	0.3	0.8	1.2	2.4	5.1	17.2	50.3	22.0	0.079	12.0	15.8	--	0.079	0.00046
±95%	0.4	--	--	0.3	0.4	0.7	1.1	2.2	7.6	15.5	18.3	38.0	0.083	5.5	14.4	--	0.086	0.00049

Table 4.2. (Continued) Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in a severely burned area of the Spring Creek watershed, 1997-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
26 May 1999 (21 days; I_{30} = 11 mm/h; P = 41.1 mm)																		
5	0.0	--	--	0.0	0.4	1.1	1.8	1.6	5.9	50.4	38.8	0.0	0.007	7.1	2.5	5.0	0.0070	0.00033
6	3.8	--	--	3.8	6.7	8.6	7.7	7.7	61.5	0.0	0.0	0.0	0.001	2.4	4.5	5.0	0.0010	0.000048
7	0.6	--	--	0.7	0.3	1.5	2.1	8.3	23.2	36.0	27.4	0.0	0.015	5.5	3.5	5.0	0.015	0.00071
8	0.4	--	--	0.0	0.0	0.0	0.4	1.5	2.6	24.0	71.0	0.0	0.011	10.4	5.4	5.0	0.011	0.00052
Mean	1.2	--	--	1.1	1.8	2.8	3.0	4.8	23.3	27.6	34.3	0.0	0.008	6.4	4.0	--	0.0085	0.00040
±95%	2.7	--	--	2.7	4.8	6.2	5.3	4.9	42.4	36.3	51.1	0.0	0.010	5.8	2.1	--	0.010	0.00048
21 July 1999 (56 days; I_{30} = 18.75 mm/h; P = 53.6 mm)																		
5	0.4	--	--	0.7	0.3	1.6	2.3	2.5	3.6	37.0	51.6	0.0	0.059	8.2	5.9	5.0	0.059	0.0011
6	0.2	--	--	0.2	0.5	1.0	1.5	1.8	6.4	20.8	12.4	55.3	0.048	17.5	3.3	5.0	0.048	0.00086
7	0.4	--	--	0.6	0.2	1.3	2.2	5.4	18.5	32.8	28.9	9.8	0.132	6.6	5.3	5.0	0.13	0.0024
8	0.0	--	--	0.0	0.3	1.5	3.0	3.0	7.7	43.4	41.0	0.0	0.039	7.2	3.4	5.0	0.039	0.00070
Mean	0.2	--	--	0.4	0.3	1.4	2.2	3.2	9.0	33.5	33.5	16.3	0.070	9.9	4.5	--	0.069	0.0013
±95%	0.3	--	--	0.5	0.2	0.4	1.1	2.6	10.7	16.3	28.2	39.8	0.067	7.8	1.9	--	0.066	0.0012
3 November 1999 (105 days; rain gage was not maintained during part of collection interval)																		
5	0.1	--	--	0.1	0.2	0.5	1.0	1.4	2.1	16.0	53.1	25.4	0.082	12.3	--	5.0	0.082	0.00078
6	0.1	--	--	0.2	0.0	0.4	0.7	1.3	7.3	25.6	64.4	0.0	0.068	9.8	--	5.0	0.068	0.00065
7	0.2	--	--	0.5	0.3	1.4	2.6	6.8	15.4	23.2	49.6	0.0	0.107	7.9	--	5.0	0.11	0.0010
8	0.4	--	--	0.6	1.3	2.3	3.7	6.5	17.6	50.9	16.7	0.0	0.016	5.4	--	5.0	0.016	0.00015
Mean	0.2	--	--	0.4	0.4	1.2	2.0	4.0	10.6	28.9	46.0	6.4	0.068	8.8	--	--	0.069	0.00064
±95%	0.2	--	--	0.4	0.9	1.4	2.2	4.0	11.2	25.1	34.3	18.3	0.066	5.0	--	--	0.068	0.00061
23 May 2000 (202 days; rain gage was not maintained during part of collection interval)																		
5													0.039	--	--	5.0	0.039	0.00019
6													0.065	--	--	5.0	0.065	0.00032
7	No Size Analysis												0.142	--	--	5.0	0.14	0.00070
8													0.007	--	--	5.0	0.0070	0.000035
Mean													0.063	--	--	--	0.063	0.00031
±95%													0.097	--	--	--	0.096	0.00048
19 November 2000 (180 days; rain gage was not maintained during part of collection interval)																		
5													0.034	--	--	5.0	0.034	0.00019
6													0.026	--	--	5.0	0.026	0.00014
7	No Size Analysis												0.197	--	--	5.0	0.20	0.0011
8													0.064	--	--	5.0	0.064	0.00036
Mean													0.080	--	--	--	0.081	0.00045
±95%													0.123	-	--	--	0.12	0.00069

[a] A rain gage malfunctioned during the collection interval and this is the maximum I_{30} for the available data.

Table 4.3. Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in an unburned area of the Spring Creek watershed, 1998-2000

[mm, millimeter; kg, kilogram; L, liter; m^2, square meter; kg/m, kilogram per meter; kg/m/d, kilogram per meter per day; days in parenthesis are the number of days between collection dates; mm/h, millimeter per hour; of, overflow; ~, approximate; I_{30}, maximum 30-minute rainfall intensity; P, total rainfall; I_{30} and P calculated from data for a rain gage about 1.3 kilometers away from the traps and listed in U.S. Geological Survey 1997, 1998, 1999, and 2000; ±95%, 95-percent confidence limits; na, not available; trap width was 1.00 m for all traps]

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
16 June 1998 (11 days; I_{30} = 13.75 mm/h; P = 14.7 mm)																		
9	0.3	--	--	1.4	4.9	10.4	18.0	28.9	30.5	5.7	0.0	0.0	0.004	1.5	0.6	5.0	0.0040	0.00036
10	0.3	--	--	0.8	1.2	1.7	4.2	9.7	22.4	59.6	0.0	0.0	0.042	4.7	1.4	5.0	0.042	0.0038
11	0.2	--	--	0.8	1.2	2.1	4.3	11.6	26.0	53.8	0.0	0.0	0.013	4.3	1.1	5.0	0.013	0.0012
12	0.8	--	--	1.9	3.7	6.3	10.9	19.4	27.3	29.8	0.0	0.0	0.019	2.5	0.6	5.0	0.019	0.0017
Mean	0.4	--	--	1.2	2.8	5.1	9.4	17.4	26.6	37.2	0.0	0.0	0.020	3.2	0.9	--	0.020	0.0018
±95%	0.4	--	--	0.8	2.7	6.3	9.9	13.8	5.8	38.8	0.0	0.0	0.027	2.3	0.6	--	0.027	0.0025
11 July 1998 (25 days; I_{30} = 7.50 mm/h[a]; P = 21.1 mm)																		
9	3.6	--	--	5.1	5.1	10.2	11.7	19.7	25.6	19.0	0.0	0.0	0.014	1.7	4.0	5.0	0.014	0.00056
10	0.8	--	--	0.8	1.9	3.4	7.3	15.7	22.2	23.8	24.1	0.0	0.026	3.8	4.7	5.0	0.026	0.0010
11	0.6	--	--	1.9	6.9	1.9	6.2	15.6	34.4	28.1	4.4	0.0	0.016	3.0	3.6	5.0	0.016	0.00064
12	6.3	0.1	6.2	5.5	6.1	10.9	13.6	20.3	20.6	13.0	3.6	0.0	0.033	1.4	5.4	5.0	0.033	0.0013
Mean	2.8	--	--	3.3	5.0	6.6	9.7	17.8	25.7	21.0	8.0	0.0	0.022	2.5	4.4	--	0.022	0.00088
±95%	4.2	--	--	3.4	3.6	6.5	5.3	3.4	9.9	10.9	17.4	0.0	0.014	1.7	1.3	--	0.014	0.00053
4 August 1998 (24 days; I_{30} = 28.50 mm/h; P = 69.1 mm)																		
9	1.2	--	--	1.2	3.5	7.1	14.1	21.2	25.9	25.9	0.0	0.0	0.008	2.1	3.3	5.0	0.008	0.0003
10	0.4	--	--	0.3	0.7	1.3	2.7	8.6	19.0	26.6	40.3	0.0	0.095	6.6	6.2	5.0	0.095	0.0040
11	0.5	--	--	0.4	0.7	2.0	4.0	11.9	36.4	44.3	0.0	0.0	0.015	3.7	2.6	5.0	0.015	0.00062
12	1.5	--	--	2.3	2.3	5.7	10.6	22.3	30.9	21.5	3.0	0.0	0.026	2.3	3.3	5.0	0.026	0.0011
Mean	0.9	--	--	1.0	1.8	4.0	7.8	16.0	28.0	29.6	10.8	0.0	0.036	3.7	3.8	--	0.036	0.0015
±95%	0.8	--	--	1.4	2.0	4.2	8.2	9.9	12.5	16.4	29.0	0.0	0.063	3.2	2.6	--	0.063	0.0026
9 September 1998 (36 days; I_{30} = 14.75 mm/h; P = 36.1 mm)																		
9	4.9	--	--	0.3	2.4	6.9	21.8	23.3	22.3	18.1	0.0	0.0	0.011	1.6	2.1	5.0	0.011	0.00031
10	0.1	--	--	0.1	0.4	1.0	3.2	5.5	13.6	28.9	24.5	22.7	0.056	7.6	4.1	5.0	0.056	0.0016
11	0.4	--	--	0.2	0.5	1.3	7.7	12.6	30.4	47.0	0.0	0.0	0.011	3.8	1.0	5.0	0.011	0.00031
12	4.1	--	--	0.4	2.0	5.2	15.8	22.3	28.5	21.7	0.0	0.0	0.022	2.0	2.7	5.0	0.022	0.00061
Mean	2.4	--	--	0.2	1.3	3.6	12.1	15.9	23.7	28.9	6.1	5.7	0.025	3.8	2.5	--	0.025	0.00071
±95%	3.5	--	--	0.2	1.4	4.2	13.4	12.8	12.1	20.8	17.6	16.3	0.032	4.3	2.2	--	0.032	0.00093
26 May 1999 (259 days; rain gage was not maintained during part of collection interval)																		
9	1.8	--	--	2.4	2.1	6.5	9.0	18.4	30.9	22.0	6.8	0.0	0.059	2.6	[b]	5.0	0.059	0.00023
10	0.6	--	--	0.8	1.0	2.7	2.2	1.9	13.4	28.7	33.8	15.1	0.068	7.8	[b]	5.0	0.068	0.00026
11	0.3	--	--	0.3	0.3	1.1	2.8	8.6	27.3	35.3	24.1	0.0	0.067	5.0	[b]	5.0	0.067	0.00026
12	1.6	--	--	1.3	3.0	4.6	8.7	16.2	26.8	27.9	10.0	0.0	0.076	3.1	[b]	5.0	0.076	0.00029
Mean	1.1			1.2	1.6	3.7	5.7	11.3	24.6	28.5	18.7	3.8	0.068	4.6	--	--	0.068	0.00026
±95%	1.1			1.5	1.9	3.9	4.9	11.9	12.6	9.6	19.4	10.9	0.012	3.7	--	--	0.012	0.000043

Table 4.3. (Continued) Summary of particle-size distribution and the flux of sediment into north-facing hillslope traps in an unburned area of the Spring Creek watershed, 1998-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.25 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
21 July 1999 (56 days; I_{30} = 18.75 mm/h; P = 53.6 mm)																		
9	1.4	--	--	3.1	1.5	5.5	10.5	16.0	25.4	31.9	4.6	0.0	0.032	2.9	4.6	5.0	0.032	0.00057
10	0.1	--	--	0.1	0.2	0.5	1.7	4.5	16.6	42.4	33.9	0.0	0.118	6.5	7.1	5.0	0.12	0.0021
11	0.4	--	--	0.6	0.2	1.4	6.2	10.1	27.5	36.8	16.8	0.0	0.020	4.4	5.1	5.0	0.020	0.00036
12	2.0	--	--	2.4	5.3	8.0	13.3	22.8	27.9	18.3	0.0	0.0	0.030	1.8	5.5	5.0	0.030	0.00054
Mean	1.0	--	--	1.6	1.8	3.8	7.9	13.4	24.4	32.4	13.8	0.0	0.050	3.9	5.6	--	0.050	0.00089
±95%	1.4	--	--	2.2	3.7	5.4	13.2	8.3	8.1	17.4	24.4	0.0	0.071	3.4	1.8	--	0.072	0.0013
3 November 1999 (105 days; rain gage was not maintained during part of collection interval)																		
9	0.6	--	--	1.3	1.3	4.4	10.8	18.7	33.1	29.8	0.0	0.0	0.033	2.8	--	5.0	0.033	0.00031
10	0.1	--	--	0.1	0.1	0.3	1.5	3.4	11.2	26.4	34.6	22.5	0.117	9.6	--	5.0	0.12	0.0011
11	0.2	--	--	0.1	0.5	1.3	3.7	11.2	29.6	47.2	6.2	0.0	0.034	4.3	--	5.0	0.034	0.00032
12	1.1	--	--	2.4	1.4	5.6	9.8	18.3	26.5	28.7	6.3	0.0	0.031	2.9	--	5.0	0.031	0.00030
Mean	0.5	--	--	1.0	0.8	2.9	6.4	12.9	25.1	33.0	11.8	5.6	0.054	4.9	--	--	0.054	0.00051
±95%	0.7	--	--	1.7	0.9	3.8	6.7	11.0	15.8	15.0	24.9	16.2	0.062	4.9	--	--	0.064	0.00058
23 May 2000 (202 days; rain gage was not maintained during part of collection interval)																		
9													0.024	--	--	5.0	0.024	0.00012
10													0.031	--	---	5.0	0.031	0.00015
11	No Size Analysis												0.013	--	--	5.0	0.013	0.000064
12													0.009	--	--	5.0	0.009	0.000045
Mean													0.019	--	--	--	0.019	0.000095
±95%													0.016	--	--	--	0.016	0.000076
19 November 2000 (180 days; rain gage was not maintained during part of collection interval)																		
9													0.071	--	--	5.0	0.071	0.00039
10													1.13[c]	--	--	5.0	na	na
11	No Size Analysis												0.050	--	--	5.0	0.050	0.00028
12													0.097	--	--	5.0	0.097	0.00054
Mean													0.073	--	--	--	0.073	0.00040
±95%													0.061	--	--	--	0.061	0.00034

[a]A rain gage malfunctioned during the collection interval and this is the maximum I_{30} for the available data.

[b]No runoff volumes were collected because this was the start of the rainfall sampling season and only the sediment from the winter season was collected.

[c]This outlier was not included and the cause for an almost 300-fold difference from the other 3 samples is unknown--vandalism is a possibility.

Table 4.4. Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in an unburned area of the Spring Creek watershed, 1998-2000

[mm, millimeter; kg, kilogram; L, liter; m^2, square meter; kg/m, kilogram per meter; kg/m/d, kilogram per meter per day; days in parenthesis are the number of days between collection dates; mm/h, millimeter per hour; of, overflow; ~, approximate; I_{30}, maximum 30-minute rainfall intensity; P, total rainfall; I_{30} and P calculated from data for a rain gage about 1.3 kilometers away from the traps and listed in U.S. Geological Survey 1997, 1998, 1999, and 2000; ±95%, 95-percent confidence limits; trap width was 1.00 m for all traps]

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
16 June 1998 (11 days; I_{30} = 13.75 mm/h; P = 14.7 mm)																		
13	0.4	--	--	1.0	1.4	2.5	5.6	10.5	38.1	40.5	0.0	0.0	0.031	3.5	2.1	5.0	0.031	0.0028
14	0.2	--	--	0.3	0.6	0.9	1.5	3.6	18.4	74.5	0.0	0.0	0.043	5.3	3.2	5.0	0.043	0.0039
15	0.2	--	--	0.4	0.7	1.2	1.8	4.2	22.2	69.3	0.0	0.0	0.039	5.1	1.5	5.0	0.039	0.0035
16	0.7	--	--	2.6	4.3	6.0	12.9	26.5	26.6	20.5	0.0	0.0	0.010	1.9	0.6	5.0	0.010	0.00091
Mean	0.4	--	--	1.1	1.8	2.6	5.4	11.2	26.3	51.2	0.0	0.0	0.031	4.0	1.8	--	0.031	0.0028
±95%	0.4	--	--	1.7	2.7	3.7	8.2	16.5	14.2	38.9	0.0	0.0	0.024	2.4	1.9	--	0.024	0.0022
11 July 1998 (25 days; I_{30} = 7.50 mm/h[a]; P = 21.1 mm)																		
13	2.5	--	--	1.7	3.8	5.9	11.9	15.7	28.0	30.5	0.0	0.0	0.024	2.6	5.6	5.0	0.024	0.00096
14	2.2	--	--	1.1	1.6	2.8	3.3	6.0	22.0	36.3	24.7	0.0	0.018	5.2	6.1	5.0	0.018	0.00072
15	0.7	--	--	0.7	1.1	1.8	3.6	10.1	34.2	45.0	2.9	0.0	0.028	3.9	5.1	5.0	0.028	0.0011
16	1.2	--	--	1.2	2.9	7.0	9.9	22.1	28.5	22.7	4.6	0.0	0.017	2.4	2.5	5.0	0.017	0.00068
Mean	1.6	--	--	1.2	2.4	4.4	7.2	13.5	28.2	33.6	8.0	0.0	0.022	3.5	4.8	--	0.022	0.00086
±95%	1.3	--	--	0.7	1.9	3.7	6.2	11.6	8.8	16.1	17.8	0.0	0.008	2.0	2.6	--	0.0079	0.00030
4 August 1998 (24 days; I_{30} = 28.50 mm/h; P = 69.1 mm)																		
13	1.1	--	--	1.6	1.4	3.2	5.3	12.4	28.8	41.0	5.3	0.0	0.044	3.7	9.9	5.0	0.044	0.0018
14	0.4	--	--	0.6	0.4	1.2	2.5	10.3	36.1	44.5	4.2	0.0	0.052	3.9	8.1	5.0	0.052	0.0022
15	0.2	--	--	0.2	1.0	1.5	2.3	8.3	34.1	45.0	7.3	0.0	0.040	4.2	6.7	5.0	0.040	0.0017
16	1.2	--	--	1.6	1.2	4.1	8.5	21.0	27.3	24.4	10.7	0.0	0.032	2.9	3.5	5.0	0.032	0.0013
Mean	0.7	--	--	1.0	1.0	2.5	4.6	13.0	31.6	38.7	6.9	0.0	0.042	3.7	7.0	--	0.042	0.0018
±95%	0.7	--	--	1.0	0.7	2.1	4.5	9.1	6.3	14.8	4.7	0.0	0.014	0.9	4.6	--	0.014	0.00065
9 September 1998 (36 days; I_{30} = 14.75 mm/h; P = 36.1 mm)																		
13	0.3	--	--	0.4	1.0	2.0	3.1	7.1	24.8	41.0	20.4	0.0	0.032	5.1	8.9	5.0	0.032	0.00089
14	0.6	--	--	0.1	0.2	0.9	2.2	9.2	30.3	49.0	7.4	0.0	0.037	4.5	5.8	5.0	0.037	0.0010
15	0.3	--	--	0.3	0.6	1.1	1.9	7.0	32.0	48.4	8.4	0.0	0.026	4.6	5.0	5.0	0.026	0.00072
16	2.7	--	--	0.0	1.2	4.5	14.4	33.3	33.2	10.9	0.0	0.0	0.009	1.8	1.9	5.0	0.0090	0.00025
Mean	1.0	--	--	0.2	0.8	2.1	5.4	14.2	30.1	37.3	9.0	0.0	0.026	4.0	5.4	--	0.026	0.00072
±95%	1.7	--	--	0.3	0.7	2.6	9.0	18.9	6.0	27.4	14.7	0.0	0.020	2.4	5.0	--	0.020	0.00054
26 May 1999 (259 days; rain gage was not maintained during part of collection interval)																		
13	0.8	--	--	1.6	0.6	3.2	5.2	11.1	30.0	37.9	9.5	0.0	0.038	3.8	[b]	5.0	0.038	0.00015
14	1.0	--	--	1.5	0.5	2.3	3.6	10.3	23.9	38.6	18.3	0.0	0.055	4.7	[b]	5.0	0.055	0.00021
15	0.6	--	--	0.9	0.7	2.5	4.4	10.6	31.5	38.2	10.5	0.0	0.042	3.9	[b]	5.0	0.042	0.00016
16	1.8	--	--	1.4	2.8	4.1	8.3	18.3	27.4	26.8	9.2	0.0	0.099	3.1	[b]	5.0	0.099	0.00038
Mean	1.0	--	--	1.4	1.2	3.0	5.4	12.6	28.2	35.4	11.9	0.0	0.058	3.9	--	--	0.058	0.00022
±95%	0.9	--	--	0.5	1.7	1.3	3.4	5.8	5.5	8.5	6.6	0.0	0.044	1.2	--	--	0.044	0.00017

Table 4.4. (Continued) Summary of particle-size distribution and the flux of sediment into south-facing hillslope traps in an unburned area of the Spring Creek watershed, 1998-2000

Trap	Percent of sample total												Sample total (kg)	D_{50} (mm)	Run-off (L)	Area (m^2)	Flux	
	Total < 0.063 mm	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm					(kg/m)	Rate (kg/m/d)
21 July 1999 (56 days; I_{30} = 18.75 mm/h; P = 53.6 mm)																		
13	0.5	--	--	0.9	0.3	1.9	3.5	7.3	22.8	41.2	21.7	0.0	0.074	5.2	10.7	5.0	0.074	0.0013
14	0.4	--	--	0.3	0.7	1.3	2.8	7.4	21.4	50.7	15.0	0.0	0.077	5.2	8.7	5.0	0.077	0.0014
15	0.3	--	--	0.5	0.2	1.0	2.3	10.3	26.7	48.1	10.6	0.0	0.085	4.7	12.0	5.0	0.085	0.0015
16	1.8	--	--	1.6	3.4	5.0	9.5	22.8	30.8	25.2	0.0	0.0	0.045	2.4	4.0	5.0	0.045	0.00080
Mean	0.8			0.8	1.2	2.3	4.5	12.0	25.4	41.3	11.8	0.0	0.070	4.4	8.9	--	0.070	0.0012
±95%	1.1			0.9	2.3	2.9	5.2	11.2	6.8	18.4	15.6	0.0	0.029	2.1	5.8	--	0.029	0.00050
3 November 1999 (105 days; rain gage was not maintained during part of collection interval																		
13	0.5	--	--	0.8	0.7	2.7	5.6	15.0	28.8	42.4	3.5	0.0	0.119	3.7	--	5.0	0.12	0.0011
14	0.4	--	--	0.6	0.3	1.2	2.7	8.2	22.3	37.3	22.8	4.3	0.132	5.5	--	5.0	0.13	0.0013
15	0.3	--	--	0.5	0.3	1.4	3.5	12.0	33.9	41.1	6.8	0.0	0.098	3.9	--	5.0	0.098	0.00093
16	0.9	--	--	1.1	1.6	3.6	7.8	21.7	63.3	0.0	0.0	0.0	0.040	2.4	--	5.0	0.040	0.00038
Mean	0.5	--	--	0.8	0.7	2.2	4.9	14.2	37.1	30.2	8.3	1.1	0.097	3.9	--	--	0.097	0.00093
±95%	0.4	--	--	0.4	0.9	1.7	3.7	9.7	29.5	30.5	16.4	3.1	0.066	2.2	--	--	0.066	0.00066
23 May 2000 (202 days; rain gage was not maintained during part of collection interval)																		
13													0.022		--	5.0	0.022	0.00011
14													0.016		--	5.0	0.016	0.000079
15						No Size Analysis							0.019		--	5.0	0.019	0.000094
16													0.028		--	5.0	0.028	0.00014
Mean													0.021		--	--	0.021	0.00011
±95%													0.009		--	--	0.0086	0.000044
19 November 2000 (180 days; rain gage was not maintained during part of collection interval)																		
13													0.332		--	5.0	0.33	0.0018
14													0.254		--	5.0	0.25	0.0014
15						No Size Analysis							0.253		--	5.0	0.25	0.0014
16													0.084		--	5.0	0.084	0.00047
Mean													0.231		--	--	0.23	0.0013
±95%													0.179		--	--	0.18	0.00096

[a]A rain gage malfunctioned during the collection interval; this is the maximum I_{30} for the available data.

[b]No runoff volumes were collected because this was the start of the rainfall sampling season and only the sediment from the winter season was collected.

Table 4.5. Summary of the seasonal flux of sediment into hillslope traps in a severely burned and an unburned area of the Spring Creek watershed, 1997-2000

[Years are water years (October through September); total summer precipitation was measured at Spring Creek above mouth near South Platte for June, July, August, and September and therefore, summer is 122 days; normalized summer flux has been normalized by the total summer precipitation; ± indicates 95% confidence limits; mm, millimeter; kg/m/d, kilogram per meter per day; kg/m, kilogram per meter; kg/m/mm, kilogram per meter per millimeter of rainfall]

	North-facing severely burned hillslope				South-facing severely burned hillslope			
	1997	1998	1999	2000	1997	1998	1999	2000
Total summer precipitation (mm)	250	151	153	185	250	151	153	185
Number of winter samples	na	1[a]	1	1	na	1[a]	3[b]	1
Number of summer samples	7	4	2	1	7	4	2	1
Average mean winter flux rate (kg/m/d)	na	0.00037	0.00022	0.000070	na	0.0010	0.00034 ±0.00039	0.00031
Average mean summer flux rate (kg/m/d)	0.047[c] ±0.96	0.0025 ±0.0031	0.00086 ±0.0056	0.00064	0.0077[c] ±0.17	0.0012 ±0.0012	0.0007 ±0.0042	0.00045
Winter flux (243 days) (kg/m)	na	0.090	0.053	0.017	na	0.24	0.083 ±1.0	0.075
Summer flux (122 days) (kg/m)	>5.7 ±120	0.30 ±0.38	0.10 ±0.68	0.078	0.94 ±21	0.15 ±0.15	0.12 ±0.51	0.055
Normalized summer flux (kg/m/mm)	0.023 ±0.48	0.0020 ±0.0025	0.00065 ±0.0044	0.00042	0.0038 ±0.083	0.00099 ±0.00099	0.00078 ±0.0033	0.00030
	North-facing unburned hillslope				**South-facing unburned hillslope**			
Number of winter samples	na	na	1	1	na	na	1	1
Number of summer samples	na	4	2	1	na	4	2	1
Average mean winter flux rate (kg/m/d)	na	na	0.00026	0.000095	na	na	0.00022	0.00011
Average mean summer flux rate (kg/m/d)	na	0.0012 ±0.00078	0.00070 ±0.0024	0.00040	na	0.0015 ±0.0012	0.0011 ±0.0017	0.0013
Winter flux (243 days) (kg/m)	na	na	0.063	0.023	na	na	0.053	0.027
Summer flux (122 days) (kg/m)	na	0.15 ±0.095	0.085 ±0.29	0.049	na	0.18 ±0.15	0.13 ±0.21	0.16
Normalized summer flux (kg/m/mm)	na	0.00099 ±0.00063	0.00056 ±0.0019	0.00026	na	0.0012 ±0.00099	0.00085 ±0.0014	0.00086

[a]The 2 October 1997 sample was used to estimate winter rates during 1997 water year.

[b] This includes 16 November 1998, 5 May 1999, and 26 May 1999.

[c]The sample collected on 04 September 1997 included the big storm of 31 August 1997. To calculate the average, the 31 August 1997 sample mean was weighted by 1 day and the average of the 7 other sample means were weighted by 121 days. The large difference between the 31 August 1997 sample and the other samples results in large values for the 95-percent confidence limits.

Table 4.6. Summary of particle-size distribution of hillslope material in the Spring Creek and the Buffalo Creek watersheds

[~ = approximately; trough refers to the hillslope sediment traps where nearby soil samples were collected; cores were 10-cm long and 5-cm in diameter; mm, millimeter; D_{50} is the median diameter; C.I., 95-percent confidence limits]

Description	Percent of total										D_{50} (mm)	Comment
	< 0.063 mm	0.063 - 0.125 mm	0.125 - 0.250 mm	0.250 - 0.500 mm	0.500 -1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm		
Unburned hillslope soil samples in the Spring Creek watershed												
Trough 9	5.9	3.2	2.4	7.6	10.9	14.9	17.7	26.0	11.4	0.0	2.6	North; 3 cores
Trough 10	5.4	2.9	2.3	4.9	7.4	12.0	21.0	25.9	18.1	0.0	3.4	North; 3 cores
Trough 11	7.6	3.2	4.6	6.2	9.0	16.0	21.3	22.9	9.1	0.0	2.3	North; 3 cores
Trough 12	9.1	4.4	3.3	6.6	8.4	14.8	21.4	21.8	10.3	0.0	2.3	North; 3 cores
Mean	7.0	3.4	3.2	6.3	8.9	14.4	20.4	24.2	12.2	0.0	2.6	--
C. I.	2.7	1.1	1.7	1.9	2.5	2.9	2.7	3.0	6.5	0.0	0.8	--
Trough 13	5.7	3.8	1.4	5.7	7.3	13.1	21.4	25.0	15.1	1.5	3.2	South; 3 cores
Trough 14	8.0	2.3	2.6	3.7	6.0	14.1	27.5	26.9	7.8	1.1	3.0	South; 3 cores
Trough 15	7.8	4.8	2.8	8.2	9.8	15.4	22.8	20.4	7.0	1.0	2.1	South; 3 cores
Trough 16	4.0	3.0	2.0	6.3	8.6	13.2	18.6	26.3	15.6	2.5	3.4	South; 3 cores
Mean	6.4	3.5	2.2	6.0	7.9	14.0	22.6	24.6	11.4	1.5	2.9	--
C. I.	2.9	1.8	1.0	3.2	2.7	1.7	6.4	4.7	6.2	1.1	0.9	--
Burned hillslope soil samples in the Spring Creek watershed												
Core 5	13.8	3.4	4.2	5.5	6.2	9.4	15.6	20.0	13.8	8.1	3.0	North; 1 core
Core 6	13.6	6.2	6.6	7.8	7.7	9.9	14.6	18.5	15.3	0.0	1.6	North; 1 core
Core 7	10.6	4.9	6.7	8.4	10.2	14.6	19.6	17.2	7.7	0.0	1.6	North; 1 core
Core 8	11.6	3.2	4.8	6.3	8.0	12.3	18.3	20.6	14.8	0.0	2.4	North; 1 core
Sci-5	12.2	3.6	4.3	4.7	5.6	9.2	16.6	24.9	19.0	0.0	3.3	North; 1 core
Mean	12.4	4.3	5.3	6.5	7.5	11.1	16.9	20.2	14.1	1.6	2.4	--
C. I.	1.6	1.5	1.3	1.9	2.3	2.8	2.6	3.9	5.8	4.1	0.9	--
Core 1	6.9	1.5	3.1	5.3	7.5	12.3	20.4	27.3	13.0	2.8	3.3	South; 1 core
Core 2	9.9	3.5	5.3	6.6	8.3	14.7	21.6	23.4	6.6	0.0	2.2	South; 1 core
Core 3	11.1	3.2	5.1	6.2	8.6	14.8	20.9	22.1	8.0	0.0	2.1	South; 1 core
Core 4	8.6	3.3	4.9	6.2	8.0	13.8	22.1	24.0	5.6	3.5	2.5	South; 1 core
Sci-1	8.5	3.1	4.8	6.8	8.6	13.5	20.4	25.1	9.3	0.0	2.5	South; 1 core
Sci-2	15.3	3.6	4.1	5.7	7.9	12.4	16.4	19.3	15.4	0.0	2.1	South; 1 core
Sci-3	10.2	2.5	3.5	4.9	6.8	11.2	16.7	22.5	21.8	0.0	3.3	South; 1 core
Sci-4	11.5	2.4	3.6	4.4	7.1	14.2	23.0	22.7	11.3	0.0	2.6	South; 1 core
Mean	10.2	2.9	4.3	5.8	7.8	13.4	20.2	23.3	11.4	0.8	2.6	
C. I.	2.4	0.6	0.6	0.7	0.5	1.0	1.9	2.3	4.7	1.0	0.3	
Unburned hillslope soil sample in Buffalo Creek watershed												
Shinglemill Creek	10.7	5.9	8.3	11.1	10.2	15.1	14.1	10.2	6.2	8.2	1.3	Area adjacent to burned area; surface sample
Burned hillslope soil samples in Buffalo Creek watershed												
Tributary 3.1	15.3	6.7	10.3	6.5	9.9	16.8	15.3	14.1	5.1	0.0	1.1	Ridge crest in burned area; surface sample
Sand Draw	3.3	3.8	7.0	9.0	14.4	18.6	22.2	16.8	5.0	0.0	1.7	Left bank; surface sample
Tributary 3.1	3.5	3.2	4.0	5.7	10.8	21.2	28.7	16.2	6.7	0.0	2.1	~100 m upstream on right bank; surface sample
Mean	7.4	4.6	7.1	7.1	11.7	18.9	22.1	15.7	5.6	0.0	1.6	--
C.I.	15.7	4.6	8.2	4.3	5.8	5.7	17.4	3.4	2.3	0.0	5.4	--

Table 4.7. Sediment size and flux data for rill traps on a south-facing hillslope in the Spring Creek watershed

[D, distance from start of rill; W, top width; P, total rainfall; I_{30} , maximum 30-minutes rainfall intensity during collection interval; V, runoff volume; m, meter; mm, millimeter, L, liter; kg, kilogram; kg/m, kilogram per meter]

Rill	D (m)	W (m)	P (mm)	I_{30} (mm/h)	V (L)	Percent the size class (mm) below is of sample total										Sample total (kg)	Flux (kg/m)
						< 0.063	0.063	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0		
									16 June 1998								
A	4	0.61	14.7	13.75	0.050	2.9	2.9	4.9	9.8	15.7	26.5	21.6	15.7	0.0	0.0	0.010	0.016
B	8	0.37	14.7	13.75	0.160	4.7	5.3	0.6	7.8	15.6	26.5	25.2	14.3	0.0	0.0	0.032	0.086
C	14	0.65	14.7	13.75	0.640	4.3	1.4	1.9	3.5	6.6	13.2	20.6	23.3	25.2	0.0	0.051	0.078
									11 July 1998								
A	4	0.61	21.1	7.50	0.130	4.3	4.3	6.5	10.9	15.2	21.7	28.3	8.7	0.0	0.0	0.005	0.0075
B	8	0.37	21.1	7.50	0.0	2.4	3.6	3.2	9.6	13.5	20.3	21.9	25.5	0.0	0.0	0.025	0.068
C	14	0.65	21.1	7.50	0.020	1.8	1.5	0.9	3.6	6.8	14.8	23.7	24.6	22.3	0.0	0.034	0.052
									4 August 1998								
A	4	0.61	69.1	28.50	2.320	6.5	2.1	4.0	7.7	11.6	22.3	21.9	9.1	1.6	13.3	0.043	0.070
B	8	0.47	69.1	28.50	8.320	8.0	3.5	4.5	8.1	13.8	21.4	23.5	12.6	4.5	0.0	0.170	0.36
C	14	0.64	69.1	28.50	6.035	8.0	1.7	2.7	4.7	7.8	15.2	23.1	20.9	15.9	0.0	0.154	0.24
									9 September 1998								
A	4	0.61	36.1	14.75	2.580	3.1	1.8	3.7	7.4	12.0	19.9	25.8	17.8	8.6	0.0	0.033	0.054
B	8	0.47	36.1	14.75	3.680	13.7	2.3	3.3	7.4	11.7	18.1	22.5	15.2	5.8	0.0	0.110	0.23
C	14	0.64	36.1	14.75	1.935	2.8	1.1	1.9	4.0	6.9	13.6	22.4	27.6	19.8	0.0	0.093	0.15
									16 November 1998								
A	4	0.61	rain gage		1.060	1.4	4.3	1.4	7.1	11.4	17.1	24.3	32.9	0.0	0.0	0.007	0.010
B	8	0.48	was not maintained		4.575	1.4	1.7	4.0	6.9	8.6	11.8	17.0	37.8	10.7	0.0	0.035	0.073
C	14	0.64	continuously		3.680	0.4	0.6	0.5	1.3	2.3	4.9	12.5	40.2	37.4	0.0	0.168	0.26
									5 May 1999								
A	4	0.59	rain gage		15.920	1.7	2.1	1.3	3.8	6.4	10.6	18.6	37.3	18.2	0.0	0.024	0.041
B	8	0.50	was not maintained		6.150	1.7	2.4	2.2	5.7	8.0	12.1	15.8	26.5	25.6	0.0	0.086	0.17
C	14	0.65	continuously		18.745	0.6	0.3	0.8	1.3	2.3	4.4	11.8	37.4	31.1	10.1	0.184	0.28
									21 June 1999								
A	4	0.59	80.5	7.75	7.400						no sediment was observed						0.00
B	8	0.50	80.5	7.75	4.050						no sediment was observed						0.00
C	14	0.65	80.5	7.75	3.950						no sediment was observed						0.00
									21 July 1999								
A	4	0.50	35.3	35.00	14.875	37.3	7.0	6.3	6.3	7.1	11.2	13.0	9.4	2.4	0.0	0.214	0.43
B	8	0.51	35.3	35.00	40.500	10.9	3.9	4.0	4.9	6.9	11.8	19.9	24.0	13.4	0.3	8.454	17.
C	14	0.45[a]	35.3	35.00	34.750	12.6	4.1	4.4	5.5	8.0	12.8	20.9	22.4	8.8	0.6	9.912	22

Table 4.7. (Continued) Sediment size and flux data for rill traps on a south-facing hillslope in the Spring Creek watershed

Rill	D (m)	W (m)	P (mm)	I_{30} (mm/h)	V (L)	Percent the size class (mm) below is of sample total										Sample total (kg)	Flux (kg/m)
						< 0.063	0.063	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0		
						3 November 1999											
A	4	0.48	rain gage		--	21.8	3.2	3.3	3.6	5.7	9.9	12.1	20.5	19.9	0.0	0.090	0.19
B	8	0.69	was not		--	11.4	3.7	4.2	5.1	7.4	13.4	19.5	21.4	12.5	1.3	2.109	3.1
C	14	0.45	maintained continuously			no water or sediment was collected											
						23 May 2000											
A	4	0.48	rain gage			no water collected and no particle size analysis										0.060	0.13
B	8	0.69	was not			no water collected and no particle size analysis										0.380	0.55
C	14	0.45	maintained continuously			no water collected and no particle size analysis										2.085	4.63
						19 November 2000											
A	4	0.48	rain gage			no water collected and no particle size analysis										0.272	0.59
B	8	0.69	was not			no water collected and no particle size analysis										1.087	1.58
C	14	0.45	maintained continuously			no water collected and no particle size analysis										0.487	1.08

[a]Sediment was deposited at the mouth of the trap, making the rill narrower and diverting sediment around trap. This represents a subsample.

Table 4.8. Comparison of the geometry of hydraulic channels formed by unsteady and steady flow processes

[c.l., confidence limits; WDR, mean width to depth ratio; A, cross-sectional area; m, meter]

Channel	Number	Typical channel slope	Top width (m)	WDR ±95%c.l.	Shape Hydraulic radius = cA^b		References
					c ±95%c.l.	b ±95%c.l.	
Rills on burned mountain slopes	71	0.40	0.20--1.10	7 ±1.2	0.22 ±0.01	0.55 ±0.02	This study.
Agricultural Rills	6	0.07	0.14--0.16	25 ±4.6	no data	no data	Elliot and others, 1989.
Agricultural Rills	unknown	0.06	no data	no data	0.50	0.64	Moore and Foster, 1990.
					0.44	0.53	Moore and Foster, 1990.
Rangeland Rills	7	0.03	0.20--0.60	31 ±11	0.18 ±0.09	0.52 ±0.09	Abrahams and others, 1996, Table III.
Powder River	20	0.001	90--260	49 ±10	0.08 ±0.02	0.60 ±0.06	Moody and Meade, 1990.
Mississippi River	8	0.00001	510--1210	58 ±15	0.05 ±0.03	0.58 ±0.06	Moody and Meade, 1993.

Table 4.9. Summary of cross-sectional area of rills in the Spring Creek watershed

[m^2, square meter]

Location	Mean cross-sectional area (m^2)	Standard deviation of the mean cross-sectional area (m^2)	Number of measurements	Comments
South-facing Hillslopes				
Rill field near hillslope traps	0.027	0.020	86	Width and maximum depth were measured along transects spaced 10 m apart down a south-facing hillslope (see map of rill field in Figure 4.4).
Rills A, B, C	0.026	0.021	27	Detailed cross sections were measured using an erosion bridge (see Table 4.7, Figure 4.5, and Appendix 2).
Rills D and E in watershed 1530 and Rill 5 in watershed 1700	0.024	0.019	23	Measured detailed cross sections using an erosion bridge on a southwest-facing hillslope.
Rill field in watershed 1530	0.010	0.0063	80	Measured several depths across each rill along transects spaced 5 m apart down a southwest-facing hillslope.
Rill 4 in watershed 1530	0.052	0.047	8	Measured detailed cross sections using an erosion bridge on a southeast-facing hillslope.
Watershed 960	0.0085	0.0082	108	On 22 different hillslopes, width and maximum depth were measured every 5 m following the rill.
South mean	0.017		332	
North-facing Hillslopes				
Watershed 1165	0.029	0.036	96	Width and maximum depth were measured on several different hillslopes within this subwatershed.
Rill 6 in watershed 1650	0.028	0.018	7	Measured detailed cross sections using an erosion bridge on a northwest-facing hillslope.
Rill field in watershed 1300	0.014	0.010	64	Several depths were measured across each rill along transects spaced 5 m apart down a northwest-facing hillslope.
Rill field in watershed 2424	0.020	0.022	182	Depth, top width, and bottom width were measured along 12 transects down a northeast-facing hillslope (data provided by K. Vincent).
North mean	0.022		349	

Section 5--CHANNELS

Methods

Main Channel

Changes in the volume of stored sediment by erosion and deposition in the main channels of Buffalo and Spring Creeks were measured from 1996 through 2000 by using aerial photogrammetry and ground surveys. Photogrammetry was used to determine cross-sectional profiles from stereo photographs taken in June 1996 (Appendix 3) after the wildfire but before the flood on 12 July 1996, and it was used to determine cross-sectional profiles from stereo photographs taken during August 1996 after the flooding. Later, a series of closely spaced channel crosssections in the study reach near the mouth of each watershed was surveyed repeatedly between June 1997 and October 2000. Valley widths were typically 25-35 m, so the surveyed cross sections were initially spaced 10 m apart to measure the volume within each study reach. Each study reach started at the mouth and extended upstream to the stream gage. The study reach in Buffalo Creek was 480 m long, and in Spring Creek 1,490 m long (fig. 5.1 and 5.2). Some cross sections were designated as permanent sections. At these sections, reference pins (4-foot, 1/2-inch rebar) were driven part way into the ground (with 0.10 to 0.30 m sticking above the ground) at each end of the cross section. Other cross sections were designated as transects for calculating volume and were marked by 8-cm x 8-cm yellow plastic flagging on stiff 30-cm long wire. Changes in volume at several adjacent cross sections or transects were very similar during 1997; in 1998, 1999, and 2000 the distance between cross sections was increased to approximately 30 m.

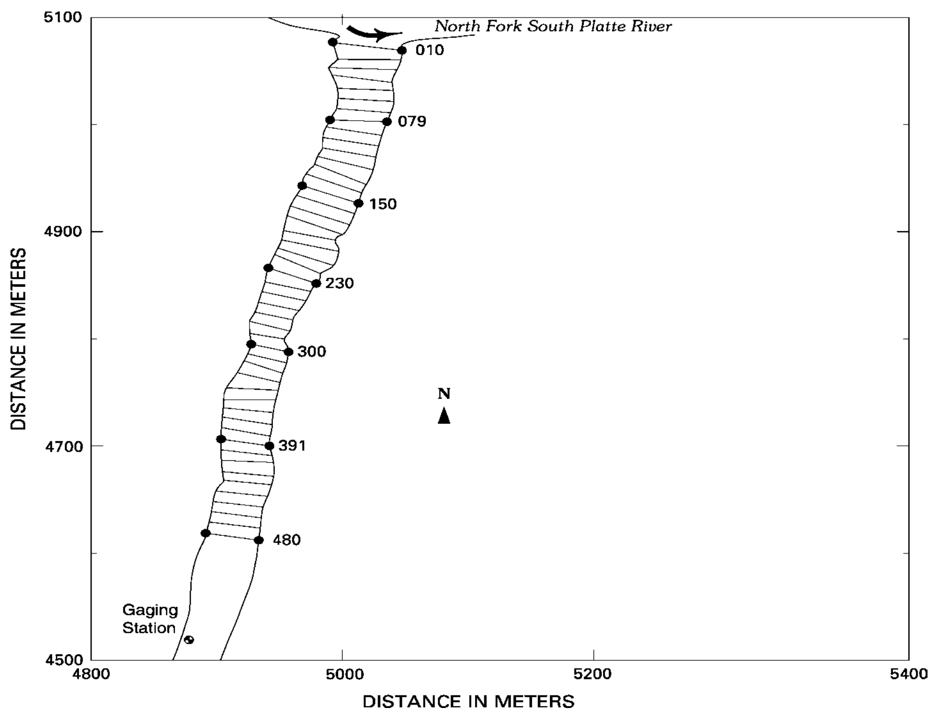


Figure 5.1. Buffalo Creek study reach. The arbitrary coordinates are shown across the bottom and along the left side. These coordinates closely approximate a true north-south, east-west coordinate system. Cross-section numbers correspond to distance upstream from the mouth of Buffalo Creek.

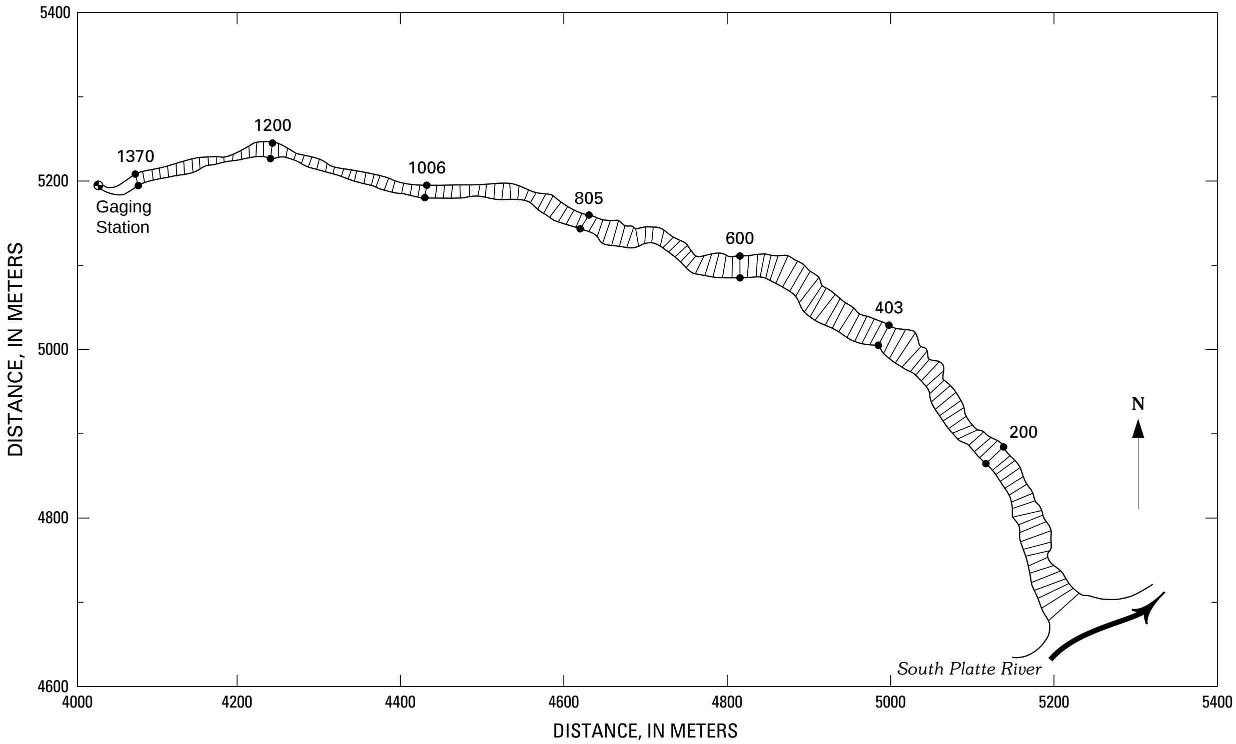


Figure 5.2. Spring Creek study reach. The arbitrary coordinates are shown across the bottom and along the left side. These coordinates closely approximate a true north-south, east-west coordinate system. Cross-section numbers correspond to distance upstream from the mouth of Spring Creek.

Initially in 1997, the relative location and elevation of each cross section and transect were measured with an electronic surveying instrument (Nikon 720 DTM), but in the following years, they were remeasured with an automatic level, metric tape, and surveying rod. The coordinate system was arbitrary but chosen to closely approximate actual geographic orientation (true east and north, and elevation above sea level). The average location of reference pins, marking the ends of the cross sections, was determined after four surveys in 1997. The adjustments required to correct each survey to the average coordinate system were calculated and listed in Appendices 4 and 5. In Spring Creek, a GPS (Global Positioning System) survey grade system (Trimble 4700 Rover and 4800 Base) was used to determine the UTM (Universal Transverse Mercator) coordinates of selected reference pins (Appendix 6). This provided data to transform the arbitrary coordinate system (*E, N,* and *Z*) to the UTM coordinate system (*E', N'*, and *Z'*) using the following equations:

$$E' = f(E\cos\theta - N\sin w\theta + d) \qquad \textbf{eq. 5. 1}$$

$$N' = f(E\sin\theta + N\cos\theta + e)\ , \qquad \textbf{eq. 5. 2}$$

$$Z' = Z - z\ , \qquad \textbf{eq. 5. 3}$$

where the scale factor, $f = 0.9992$, the rotation angle, $\theta = 2.67^{o}$, the east offset, $d = 480763.458$ m, the north offset, $e = 4358567.611$ m, and the elevation offset, $z = 120.70$ m. These equations were used to compute the UTM coordinates for the reference pins in Spring Creek (Appendix 7).

The UTM coordinates permitted the comparison of cross-sectional profiles measured in 1996 by photogrammetry with cross-sectional profiles measured in 1997 by ground survey. For both Buffalo and Spring Creek watersheds, all the cross section and transect data (listed in files on the accompanying CD) are in the arbitrary coordinate system, and the format for the files is given in Appendices 8 and 9.

Subwatersheds

Erosion in drainages was measured in two Spring Creek subwatersheds (fig. 5.3) in 1999. One subwatershed, W960, is a south-facing, third-order (Strahler, 1952) watershed with an area of 7.0 ha. Its mouth is on the left bank 960 m upstream from the mouth of Spring Creek, and it has an estimated channel density of 21 km/km^2 after the fire. Watershed W1165 is a north-facing, fourth-order watershed with an area of 3.7 ha. It is on the right bank, 1,165 m upstream from the mouth of Spring Creek and has an estimated channel density of 48 km/km^2.

Drainages may be either unchannelized with no inflection point in a cross-sectional profile, or they may be channelized with at least two inflection points forming a bank. Estimates of drainage erosion included pre-fire channels and unchannelized drainages channelized by post-fire erosion. Cross-sectional erosion (volume of stored sediment lost per unit channel length or the cross-sectional area) was measured every 5 m along all drainages in these subwatersheds. The pre-flood land surface was estimated by extrapolating the post-flood land surface across the channel. This was aided in many places by using tree roots left exposed after the floods. These roots, in some cases, were unbroken and spanned the entire channel. Files of the basic data collected to calculate the erosion volumes are on the accompanying CD and the file formats are listed in Appendix 11.

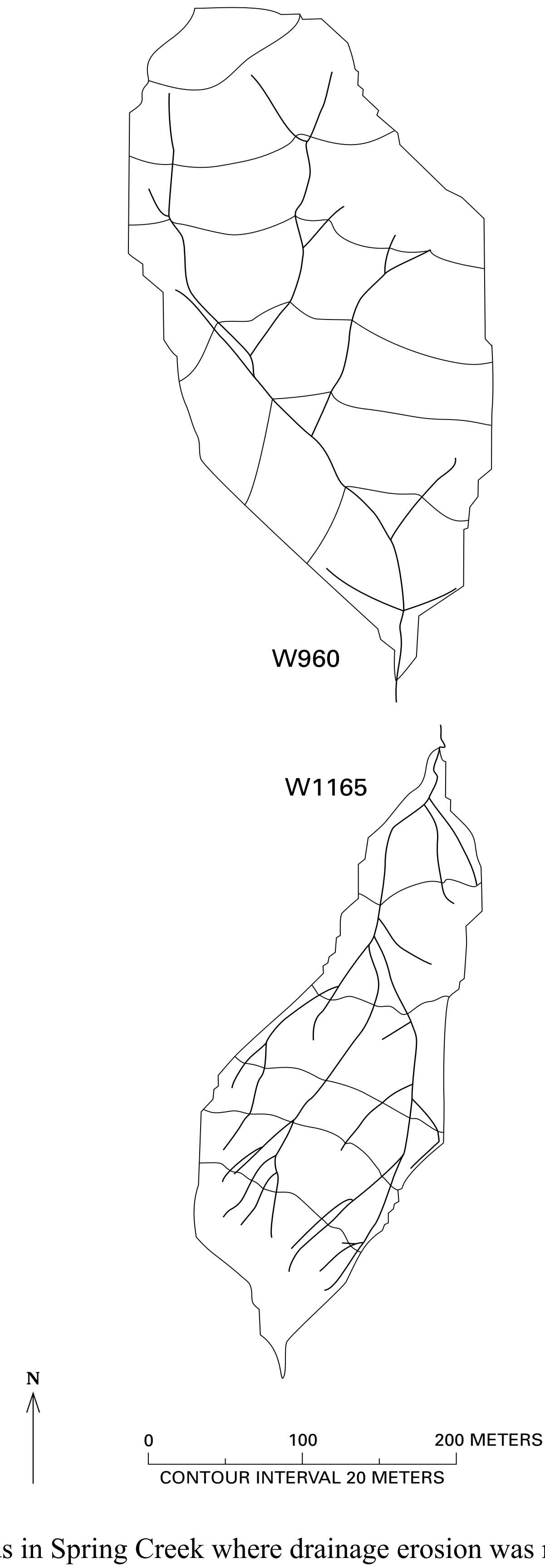


Figure 5.3. Subwatersheds in Spring Creek where drainage erosion was measured. Watershed 960 is a third-order watershed and watershed 1165 is a fourth-order watershed.

Results

Main Channel

The primary erosional event was the thunderstorm on 12 July 1996, which was approximately a 100-yr, 1-hour rainstorm based on maximum 30-minute rainfall intensities predicted by empirical equations developed from 6- and 24-hour precipitation data (Hershfield, 1961; Miller and others, 1973). In the Buffalo Creek watershed, sediment eroded from subwatersheds was deposited as alluvial fans at the mouth of each tributary. Sediment thickness decreased in the main channel downstream from each fan. Although the Buffalo Creek flood plain was buried near the mouth of each tributary, it was, in general, preserved throughout the length of the valley. However, the erosion and deposition in the main, east-west trending channel of Spring Creek was much different. Initial erosion occurred across the entire valley and removed any pre-existing flood plain. Alluvial fans were deposited at the mouths of tributaries and were connected to the channel sediment deposits, which were as thick as 4 m. This deposition produced a sediment superslug (Nicholas and others, 1995) in Spring Creek occupying about 5,000 m along the main channel and extending across the entire valley.

Net erosion and net deposition for various time intervals between June 1996 and May 2000 were determined by calculating the difference in elevations at cross sections between successive surveys. Erosion and deposition following the flood on 12 July 1996 were determined by differencing 58 cross sections near the mouth of Spring Creek (Appendix 7). The elevations were determined by photogrammetry using stereo photographs taken on 2 June 1996 and 2 August 1996. This photogrammetric data had a resolution of about ± 0.1 m in both the vertical and horizontal direction. Erosion and deposition areas for a few cross sections are listed in table 5.1, and profiles for three cross sections at four different times are shown in figure 5.4. Depositional thickness varied throughout the study reach. For example, the maximum depositional thickness at section 187 was about 0.5 m where the valley is wide (fig. 5.5A). Where the valley is narrower at section 1200, the maximum depth was about 2.0 m. Similarly, the mean thickness would depend on the valley width so that the equivalent thickness at each cross section was calculated by dividing the area of erosion (negative) or deposition (positive) by the mean valley width (27 m, fig. 5.5A). Thus, the equivalent thickness for the superslug created by the rainstorm increases downstream and reaches a maximum of 2.6 m at the mouth of Spring Creek (fig. 5.5B). The reach average equivalent thickness for the entire study reach was 0.54 m. The cumulative thickness increased until 31 August 1997 and then remained approximately constant (table 5.2). Similar data for Buffalo Creek (table 5.3) indicate very little change in thickness within the study reach. Net erosion and deposition at each surveyed cross section in Spring Creek have been calculated for all time intervals between surveys (see selected cross sections in table 5.1 and Appendix 10). The equivalent thickness is plotted as a function of distance in figure 5.6 for successive time intervals.

No translational sediment wave was observed to propagate downstream, which in figure 5.6 would appear as a slug, or peak, moving from right to left (along the spatial axis) and from top to bottom (along the time axis). No diffusing stationary wave was evident. These results emphasize the unsteady nature of the sediment transport (Moody, 2001). This is probably a result of the unsteady character of the flow. In this case, prolonged periods of shallow flow over large relative roughness are suddenly interrupted by short periods of flash floods, in contrast to the steady character of perennial rivers.

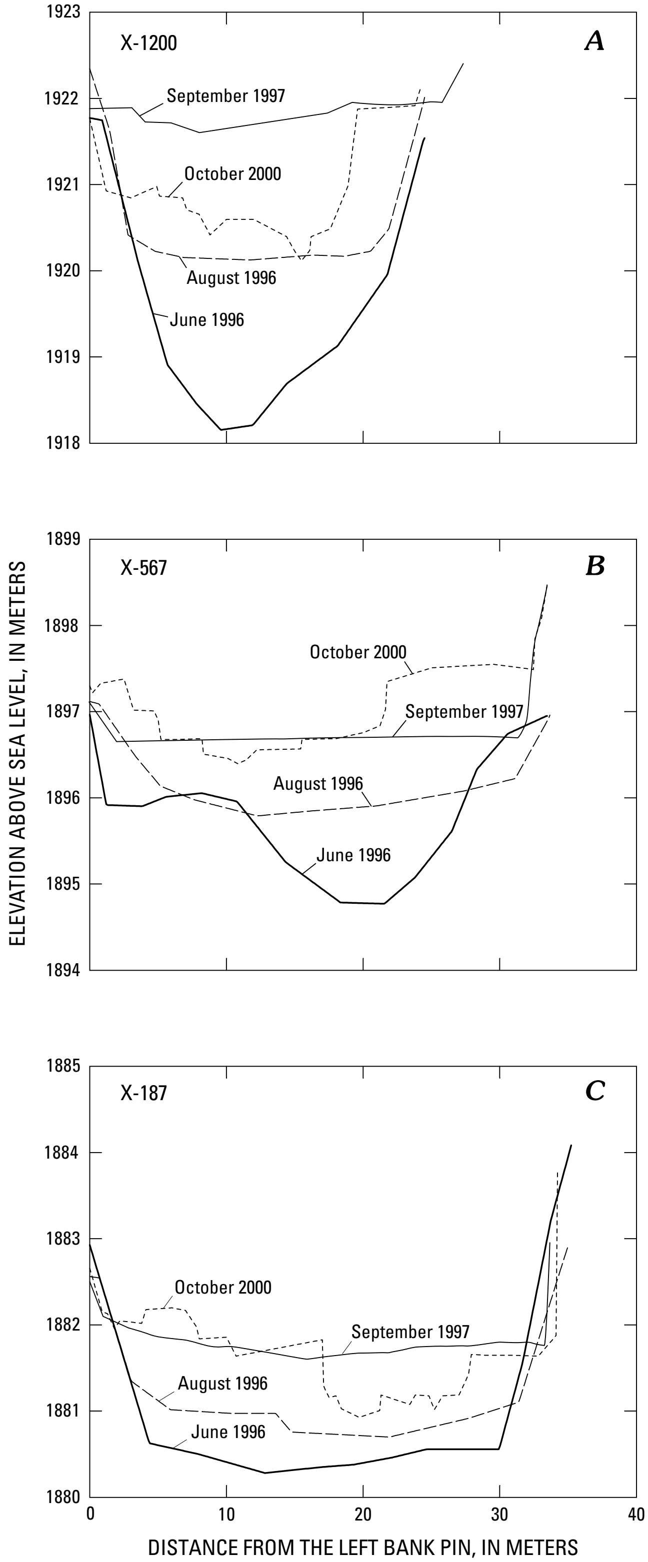


Figure 5.4. Three representative cross sections in Spring Creek. Profiles for June 1996 are based on photogrammetry and represent the morphology after the wildfire but before the erosion caused by intense rainstorms in June and July 1996. Profiles for August 1996 are based on photogrammetry and represent the morphology after the erosion caused by intense rainstorms and flooding in June and July 1996. Profiles for September 1997 are based on ground surveys and represent the morphology after the flash flood on 31 August 1997. Profiles for October 2000 are based on ground surveys and represent the morphology after a relatively long period with no significant flash floods.

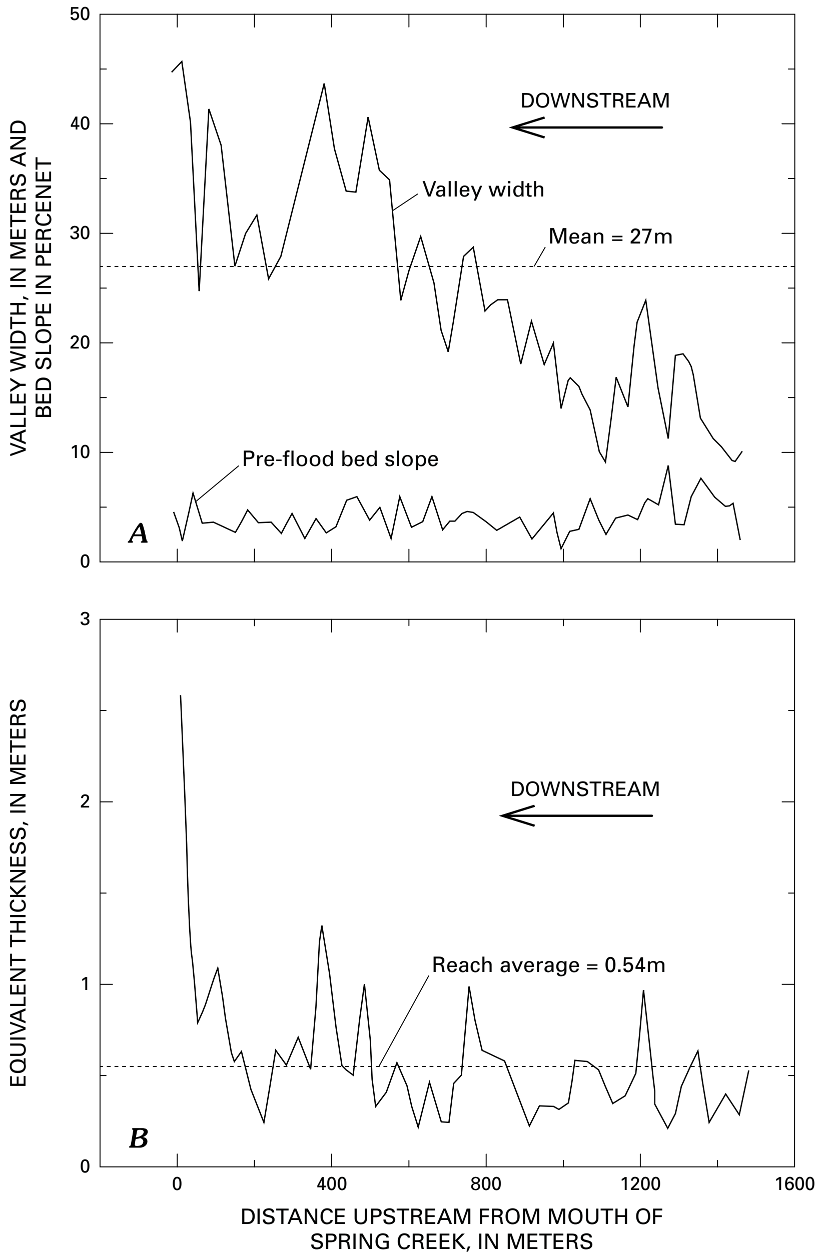


Figure 5.5. A. Variations in the valley width of Spring Creek and the pre-flood bed slope in June and July 1996. A. Valley width. The average valley width is 27 m. B. The equivalent thickness of sediment deposited after the flooding in June and July 1996 and covering a width equal to the average valley width.

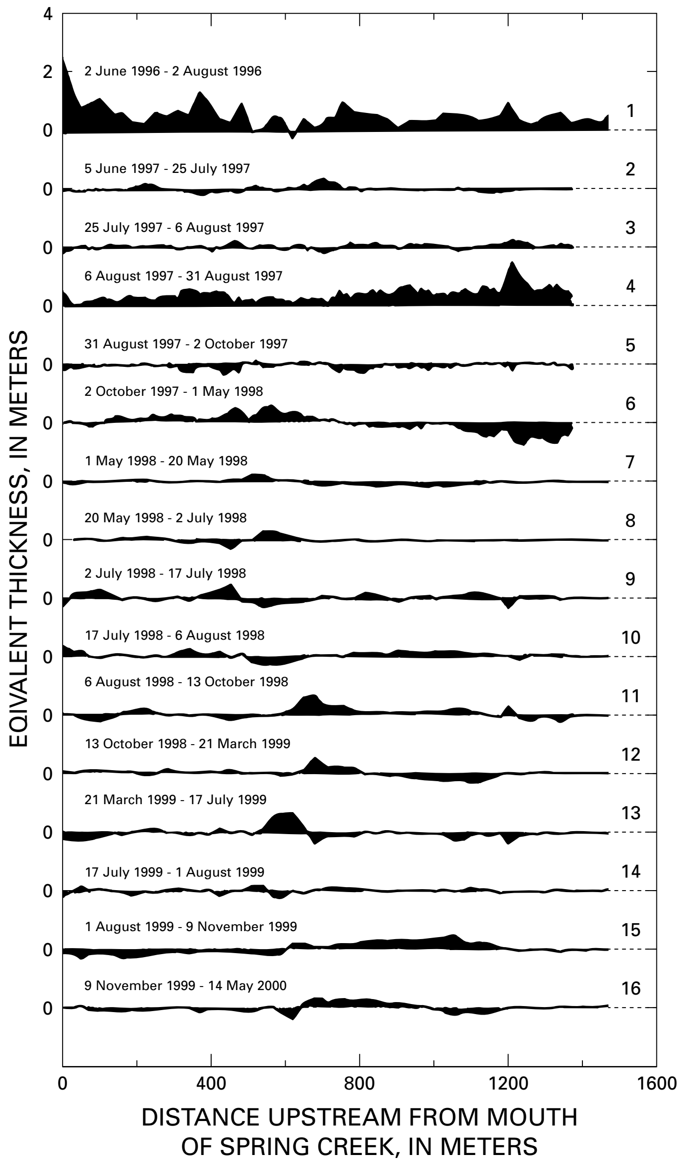


Figure 5.6. Changes in erosion (negative) and deposition (positive) as a function of time and distance upstream from the mouth of Spring Creek. Change is expressed as the equivalent thickness of sediment eroded or deposited between two successive surveys over a width equal to the average valley width (27 m). The same vertical scale is used for each time interval as shown for 2 June 1996 - 2 August 1996.

Subwatersheds

Erosion of unchannelized and channelized drainages after the 1996 wildfire was greater than deposition in the two subwatersheds (W960 and W1165) that were studied. The south-facing watershed (W960) had a net erosion of 1,800 m^3, and the north-facing watershed (W1165) had net erosion of 470 m^3 of sediment. Sediment erosion, however, was not spread evenly among the channels within the watershed. Some first-order channels often resembled rills in size. These first-order channels appear to be created by water discharged from a series of converging rills occupying a hollow (Welter, 1995) at the head of the first-order channel. From 7 to 9 percent of the eroded sediment came from first-order channels and 16 to 22 percent came from second-order channels (table 5.4). The majority (about 70 percent) of the eroded sediment came from third- and fourth-order channels, similar to observations made in the Snowy Mountains of Australia (Brown, 1972). The average equivalent sediment yield (area weighted) from channels in these two subwatersheds was 210 m^3/ha.

One purpose for measuring these areas of erosion was to explore what possible topographic variables might be useful in predicting erosion on a watershed scale. Four possible variables were considered, contributing area, *A;* cumulative stream length upstream from the measurement location, *L*; local channel slope, *B;* side slope of the channel on both sides, ϕ_1 and ϕ_2; and the top width, *w* (Appendix 11). Contributing area is a possible variable because water discharge, velocity, and shear stress in the channel depend on rainfall volume, which depends on contributing area. Cumulative stream length was considered as a possible surrogate for contributing area and has the advantage that it is easier to measure. Top width has the disadvantage in that it cannot be measured until after an erosional event, so measurements of erosion were regressed against contributing area and slope. Analysis indicated that the local slope had less effect on determining erosion than contributing area. Erosion in W960 was related to contributing area (fig. 5.7) and cumulative stream length (fig. 5.8) by

$$E = 5.1x10^{-4}A^{0.81} \qquad r^2 = 0.73 \,, \qquad \textbf{eq. 5. 4}$$

$$E = 7.6x10^{-3}L^{0.84} \qquad r^2 = 0.72 \,. \qquad \textbf{eq. 5. 5}$$

and the erosion in W1165 was given by

$$E = 7.7x10^{-4}A^{0.66} \qquad r^2 = 0.61 \qquad \textbf{eq. 5. 6}$$

$$E = 4.7x10^{-3}L^{0.69} \qquad r^2 = 0.66 \qquad \textbf{eq. 5. 7}$$

In addition, the top width was related to the cumulative stream length (fig. 5.9). For W960 the equation is:

$$w = 0.23L^{0.41} \qquad r^2 = 0.68 \qquad \textbf{eq. 5. 8}$$

and for W1165 it is:

$$w = 0.15L^{0.39} \qquad r^2 = 0.67 \qquad \textbf{eq. 5. 9}$$

These equations indicate that the cumulative stream length is a possible surrogate for contributing area as well as channel top width. Some of the variability of top width is probably caused by different side slopes of the channel.

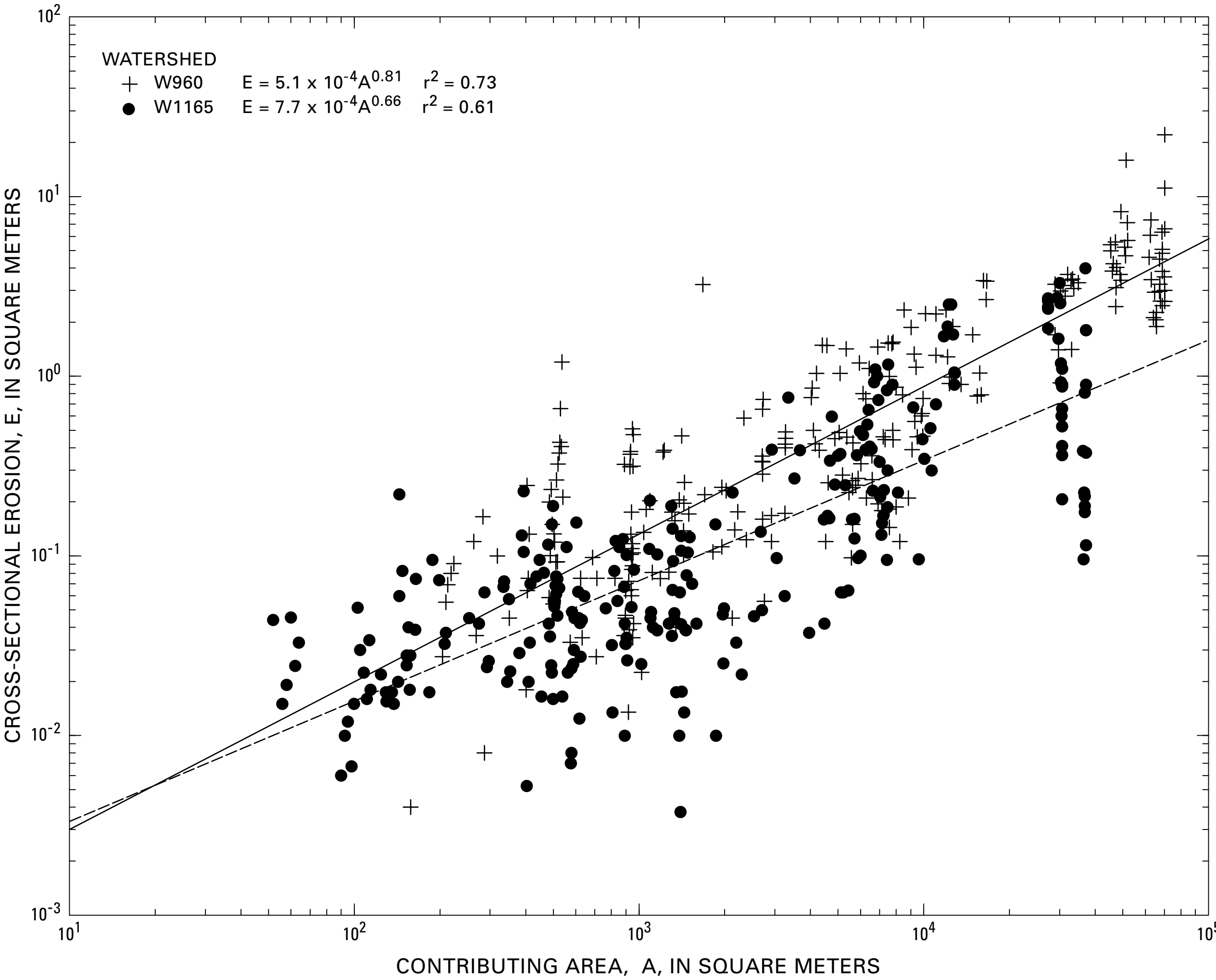


Figure 5.7. Erosion of sediment as a function of contributing area. Measurements were made at 5-m intervals along all channels after the intense rainstorms in 1996 and 1997. The dotted line represents W1165 and the solid line represents W960.

At present, contributing area or cumulative stream length can be used to provide initial estimates of the relative erosion. The differences in the relations for the south-facing watershed W960 (eqs. 5.4 and 5.5) and the north-facing watershed W1165 (eqs. 5.6 and 5.7) may indicate that the detachment properties of the soil types are different. If these soil properties were included more accurate erosional amounts might be predicted. Finally, the absolute erosional amounts will also depend upon the depth of rainfall for a given event and the subsequent depth of flow in the channels. It must be remembered that these data were collected after two large rainstorms (12 July 1996 and 31 August 1997) that were primarily erosional events in these relatively small subwatersheds. Smaller rainstorms were observed to produce both erosion and deposition in the subwatersheds. Therefore, including rainfall intensities and total amounts of precipitation should also improve the accuracy of the predictions. However, contributing area and cumulative stream length can be measured from a digital elevation model, unlike soil detachment and rainfall, and the empirical relations above can give initial estimates of the relative erosion for large rainstorms.

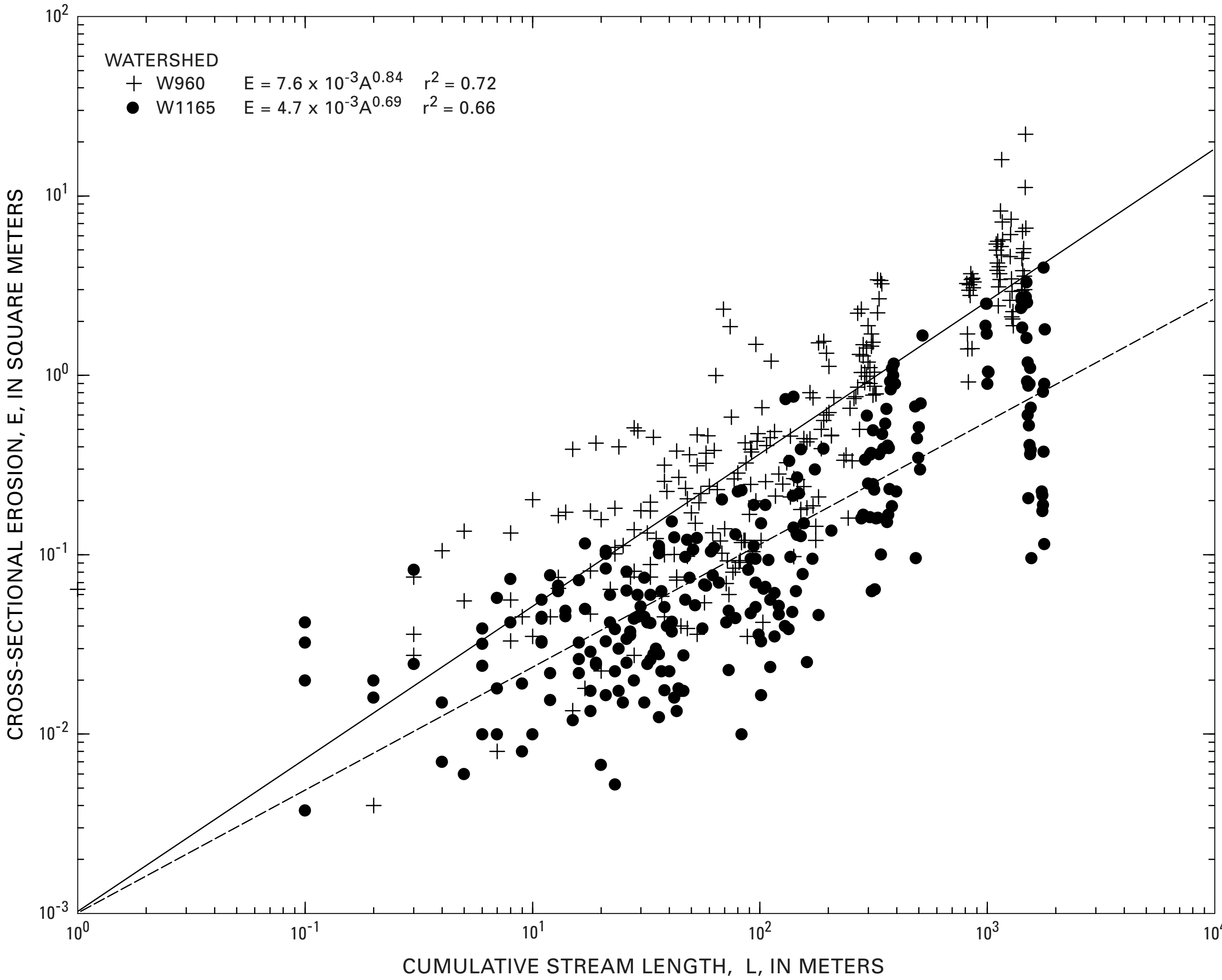


Figure 5.8. Erosion of sediment as a function of cumulative stream-length. Measurements were made at 5-m intervals along all channels in subwatersheds W960 and W1165 in the Spring Creek watershed after the intense rainstorms in 1996 and 1997. The dotted line represents W1165 and the solid line represents W960.

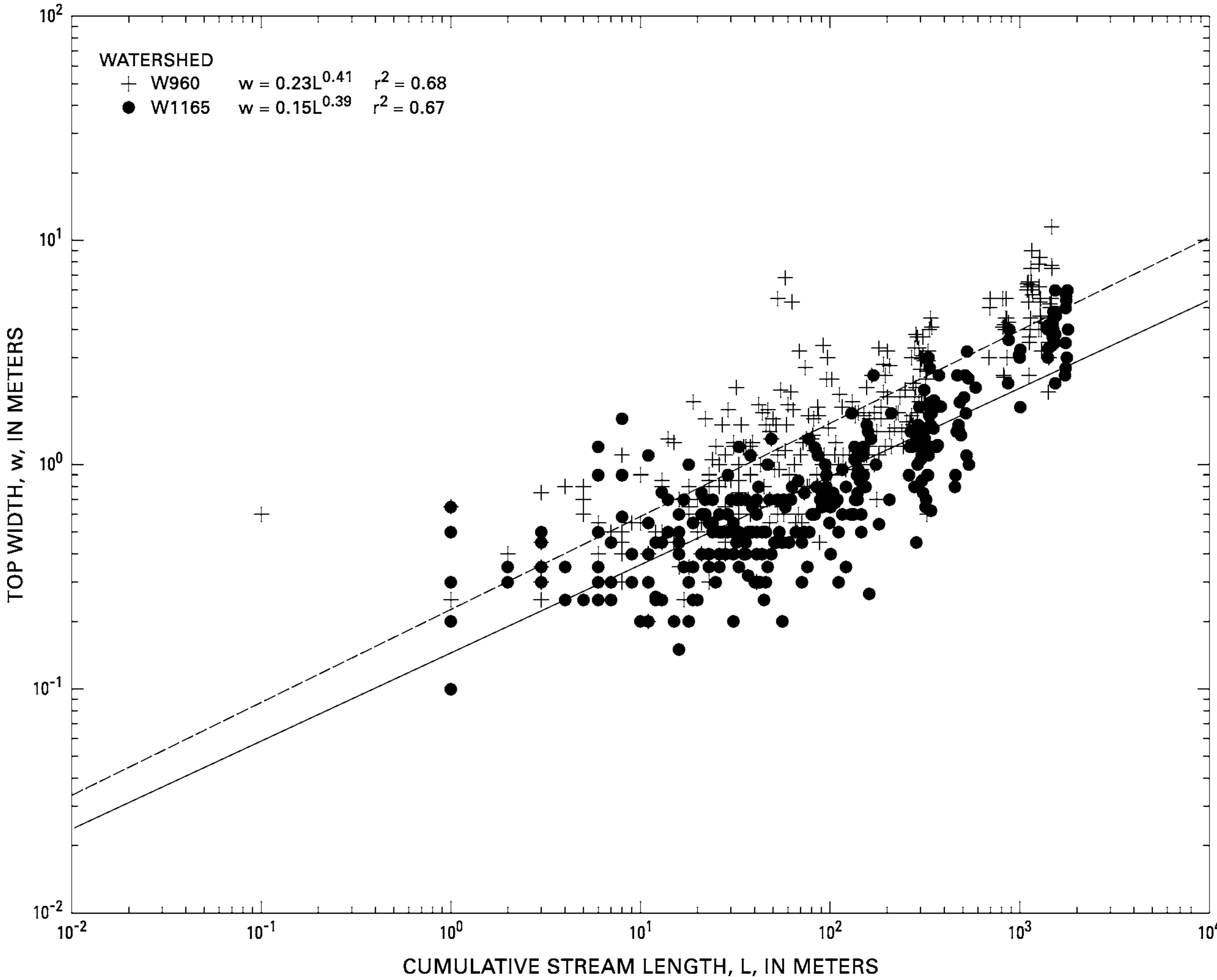


Figure 5.9. Relation between channel top-width and cumulative stream-length. Measurements were made at 5-m intervals along all channels in subwatersheds W960 and W1165 in the Spring Creek watershed after the intense rainstorms in 1996 and 1997. The dotted line represents W1165 and the solid line represents W960.

Table 5.1. Erosion and deposition at selected channel cross-sections in the Spring Creek study area

[Numbers in table represent change in cross-sectional area in square meters (m^2); Eros.,net cross-sectional area of erosion; Dep., net cross-sectional area of deposition; ns, not surveyed]

Dates	Channel cross sections																	
	-2.7		187		341		567		679		815		1006		1200		1450	
	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.	Eros.	Dep.
2 June1996 2 August 1996	0.0	69.7	3.0	11.4	0.0	14.2	2.1	15.1	3.7	6.5	0.7	16.1	0.9	10.4	0.0	25.8	0.3	7.3
2 August 1996 5 June 1997	15.5	14.9	0.0	13.9	0.4	4.0	1.6	3.6	0.1	6.5	2.1	1.2	0.0	8.4	1.2	0.9	ns	ns
5 June 1997 25 July 1997	1.1	0.0	0.7	1.4	2.6	0.1	1.4	0.8	0.4	7.2	0.4	0.3	0.8	0.5	2.2	0.4	ns	ns
25 July 1997 6 August 1997	6.3	0.6	1.6	1.7	2.3	3.2	0.9	2.0	1.3	0.1	0.6	2.5	0.0	2.0	0.3	5.1	ns	ns
6 August 1997 31 August 1997	5.9	19.9	1.0	9.0	0.3	15.6	1.0	8.8	0.4	6.6	1.1	11.3	0.2	11.0	0.2	30.5	ns	ns
31 August 1997 2 October 1997	5.0	0.0	0.8	0.0	7.2	0.0	2.5	0.0	0.0	0.0	7.2	0.0	1.6	0.0	0.0	0.5	ns	ns
2 October 1997 1 May 1998	1.6	1.0	0.7	2.1	1.6	6.2	0.1	14.4	0.1	3.8	1.5	0.4	1.3	0.1	10.1	3.0	ns	ns
1 May 1998 20 May 1998	1.3	0.9	0.4	1.8	0.8	1.2	1.0	2.6	2.0	0.1	3.1	0.2	2.7	0.1	0.3	0.3	0.3	0.7
20 May 1998 2 July 1998	ns	ns	0.6	1.7	0.6	1.6	0.0	7.4	1.5	0.0	1.7	0.3	0.4	0.1	0.4	0.5	0.6	0.3
2 July 1998 17 July 1998	11.4[a]	2.9[a]	1.9	2.4	3.2	0.8	7.1	0.4	1.4	0.3	1.0	5.5	2.1	1.2	9.8	1.0	0.2	0.2
17 July 1998 6 August 1998	2.7	12.0	0.8	0.8	0.4	7.0	8.5	1.3	1.3	2.5	0.3	2.6	0.1	4.7	2.5	3.0	0.3	0.4
6 August 1998 13 October 1998	1.1	0.9	0.7	4.1	1.6	0.3	1.7	1.0	0.0	17.9	0.2	1.7	0.1	2.4	0.8	8.3	0.6	0.2
13 October 1998 21 March 1999	1.4	2.2	1.8	2.5	0.8	0.7	1.3	1.3	0.0	13.6	2.9	1.4	6.1	0.1	0.2	0.2	0.4	0.4
21 March 1999 17 July 1999	6.0	0.4	1.8	2.2	4.8	2.3	0.0	14.8	10.0	0.0	1.8	2.5	1.9	0.8	10.0	0.2	0.5	0.5
17 July 1999 1 August 1999	6.5	1.0	4.5	0.2	1.1	1.6	5.4	0.0	0.9	1.8	0.9	1.9	1.3	0.6	2.7	1.7	0.3	0.3
1 August 1999 8 November 1999	3.7	0.7	7.2	0.1	4.1	0.2	8.2	2.6	0.4	2.0	0.1	6.7	0.1	9.7	3.0	3.1	0.4	0.2
8 November 1999 14 May 2000	1.2	0.6	2.4	0.2	1.2	0.9	0.9	1.4	0.0	8.3	0.1	7.2	2.5	0.1	0.7	0.3	0.1	1.3
14 May 2000 21 October 2000	1.1	1.7	1.7	1.0	1.9	1.1	1.6	0.4	1.5	0.7	0.2	3.7	1.4	0.3	4.3	1.5	1.1	0.6

[a]Change between 20 May 1998 and 17 July 1998.

Table 5.2. Change in volume of sediment stored in the channel near the mouth of Spring Creek

[m, meter; m^3, cubic meter; equivalent thickness, volume change divided by the product of the mean width (27 m) and the length of the surveyed channel]

Channel survey		Elapsed time (days)	Number of cross sections	Volume change ΔV (m^3)	Length of surveyed channel (m)	Equivalent thickness (m)	Cumulative thickness (m)	Comments
Starting date	Ending date							
2 June 1996	2 August 1996	61	58	21,800	1,490	0.54	0.54	Volumes were based on photogrammetry method.
2 August 1996	5 June 1997	307	54	5,970	1,390	0.16	0.70	Volumes were based on photogrammetry and channel survey.
5 June 1997	25 July 1997	50	142	89.2	1,390	0.0024	0.70	
25 July 1997	6 August 1997	12	142	1,260	1,390	0.034	0.73	Flash floods were on 29 and 31 July 1997.
6 August 1997	31 August 1997	25	142	17,720	1,390	0.47	1.20	Flash flood was on 31 August and volume was 14,920 m^3 in the channel plus 2,800 m^3 in the South Platte River.
31 August 1997	2 October 1997	32	142	-2,920	1,390	-0.078	1.12	
2 October 1997	1 May 1998	211	142	-1,330	1,390	-0.035	1.08	Estimated 60 days of active sediment transport.
1 May 1998	20 May 1998	19	54	-870	1,490	-0.022	1.06	
20 May 1998	2 July 1998	43	44	-100	1,440	-0.003	1.06	
2 July 1998	17 July 1998	15	45	520	1,490	0.013	1.07	Flash flood was on 9 July.
17 July 1998	6 August 1998	20	56	1,300	1,490	0.032	1.10	Flash flood was on 31 July.
6 August 1998	13 October 1998	68	59	1,370	1,490	0.034	1.13	
13 October 1998	21 March 1999	159	58	-800	1,490	-0.020	1.11	
21 March 1999	17 July 1999	118	58	-880	1,490	-0.022	1.09	
17 July 1999	1 August 1999	15	58	-80	1,490	-0.002	1.09	Flash flood was on 29 July and eroded 410 m^3 between the mouth and section 679 upstream from the mouth. It deposited 330 m^3 between sections 679 and 1470.
1 August 1999	8 November 1999	99	58	850	1,490	0.021	1.11	
8 November 1999	14 May 2000	188	57	-410	1,470	-0.010	1.10	
14 May 2000	21 October 2000	160	17	-380	1,450	-0.010	1.09	

Table 5.3. Change in volume of sediment stored in the channel near the mouth of Buffalo Creek

[m, meter; m^3, cubic meter; equivalent thickness = volume change divided by the product of the mean width (35 m) and the length of the surveyed channel]

Channel survey: Starting date	Channel survey: Ending date	Elapsed time (days)	Number of cross sections	Volume change (m^3)	Length of surveyed channel (m)	Equiv-alent thickness (m)	Cumula-tive thickness (m)	Comments
14 June 1997	20 July 1997	36	48	1,120	470	0.068	0.068	
20 July 1997	11 August 1997	22	48	-25	470	-0.002	0.066	Flash floods were on 28, 29 July and 2 August.
11 August 1997	8 May 1998	270	48	370	470	0.022	0.088	Flash floods were on 26, 31 August.
8 May 1998	21 July 1998	74	27	-3,680	470	-0.22	-0.13	Average runoff was in May (1.68 m^3/s) which was greater than the other months in 1998.
21 July 1998	7 August 1998	17	16	2,310	470	0.14	0.01	Flash flood was on 31 July.
7 August 1998	17 October 1998	71	16	210	470	0.013	0.013	

Table 5.4. Characteristics and erosion volumes for drainages in two subwatersheds in the Spring Creek watershed

[km, kilometer; m, meter; m^2, square meter; m^3, cubic meter; %, percent; Erosion measurements were made after two major rainstorms on 12 July 1996 and 31 August 1997; Watershed number refers to distance, in meters, upstream from the mouth of Spring Creek]

Characteristic	Watershed 960	Watershed 1165
General aspect	South facing	North facing
Area (hectares)	7.01	3.72
Percent of Spring Creek watershed	0.26	0.14
Order	3	4
Number of channel links	20	37
Total stream length (km)	1.47	1.80
Stream density (km/km^2)	21	48
Overland flow length =1/(2 x stream density) (m)	24	10
Critical area for channel initiation		
minimum area (m^2)	63	51
average area (m^2) ± standard deviation	400±330	230±230
Total net erosion volume (m^3)	1800	470
1st-order channels (%)	7	9
2nd-order channels (%)	22	16
3rd-order channels (%)	71	18
4th-order channels (%)	none	57
Sediment Yield (m3/hectare)	257	126

Section 6--SEDIMENT TRANSPORT

Methods

Bed Material

The character of the bed material in Buffalo and Spring Creeks was determined from surficial samples collected near the mouth of two tributaries to Buffalo Creek, and from samples collected at or near the mouth of Buffalo and Spring Creeks (table 6.1). Eight surficial samples were collected in Spring Creek along the main channel to determine the downstream variation in grain sizes of the sediment deposited after the floods in 1996 and 1997 (table 6.2). Particle-size distributions were determined by sieving all sediment samples using a RoTap equipment for 15-20 minutes, weighing, and reporting by whole phi sizes (Guy, 1969). The Cory shape factor is given by:

$$S_c = \frac{\gamma}{\sqrt{\alpha\beta}}, \qquad \textbf{eq. 6.1}$$

where α, β, and γ are diameters of a particle from smallest to largest axes. This was measured for one size class of sediment diameters from Spring Creek (11.3-16 mm).

Direct Measurements

A sediment rating curve was established for the mouth of each watershed by collecting bed-load and suspended-load samples and by measuring the water discharge at selected times over a four-year period (1997-2000). Additionally, estimates of the total sediment transport rates were made for high flows for selected flash floods based on indirect measurements discussed as follows: For low flows, bed load was collected during steady-flow conditions using a modified Helly-Smith bed-load sampler (Emmett, 1980; Hubbell and others, 1986) referred to as the US BLH-84 (fig. 6.1A) (Druffel and others, 1976; U.S. Geological Survey, 1990; Ryan and Porth, 1999). This was made from 1-mm thick, stainless-steel sheet metal so that the predominant sand- and gravel-size particles would not accumulate at the lip of the sampler and, thus, underestimate the bed load. It had the standard 76.2-mm-square opening but was made with the 1.40 expansion ratio nozzle to eliminate backwater effects from using the sampler in the relatively narrow channels (1-2 m). A 0.250-mm, nylon-mesh net was attached to the US BLH-84 sampler. Four replicates (grain size> 0.250 mm) were collected each time the bed load was sampled. These replicates were dried at 105^{o}C and sieved (using a RoTap for 15-20 minutes) by whole phi intervals ($\Phi = Log_2 D$, where D is the particle diameter in millimeters, Krumbein, 1934). The resultant data are listed in tables 6.3 and 6.4.

Suspended load was collected between each bed-load replicate using a 450-mL pint jar fitted with a cap and a 3-mm-diameter isokinetic nozzle (fig. 6.1B) (Edwards and Glysson, 1988; Meade and Stevens, 1990). The suspended sediment was wet sieved by whole phi intervals, filtered through preweighted Millipore HA filters (0.45-micron pore size), dried at 105^{o}C, and weighed to within 0.01 mg. The preweighed mass of the filter was subtracted to obtain the mass of sediment.

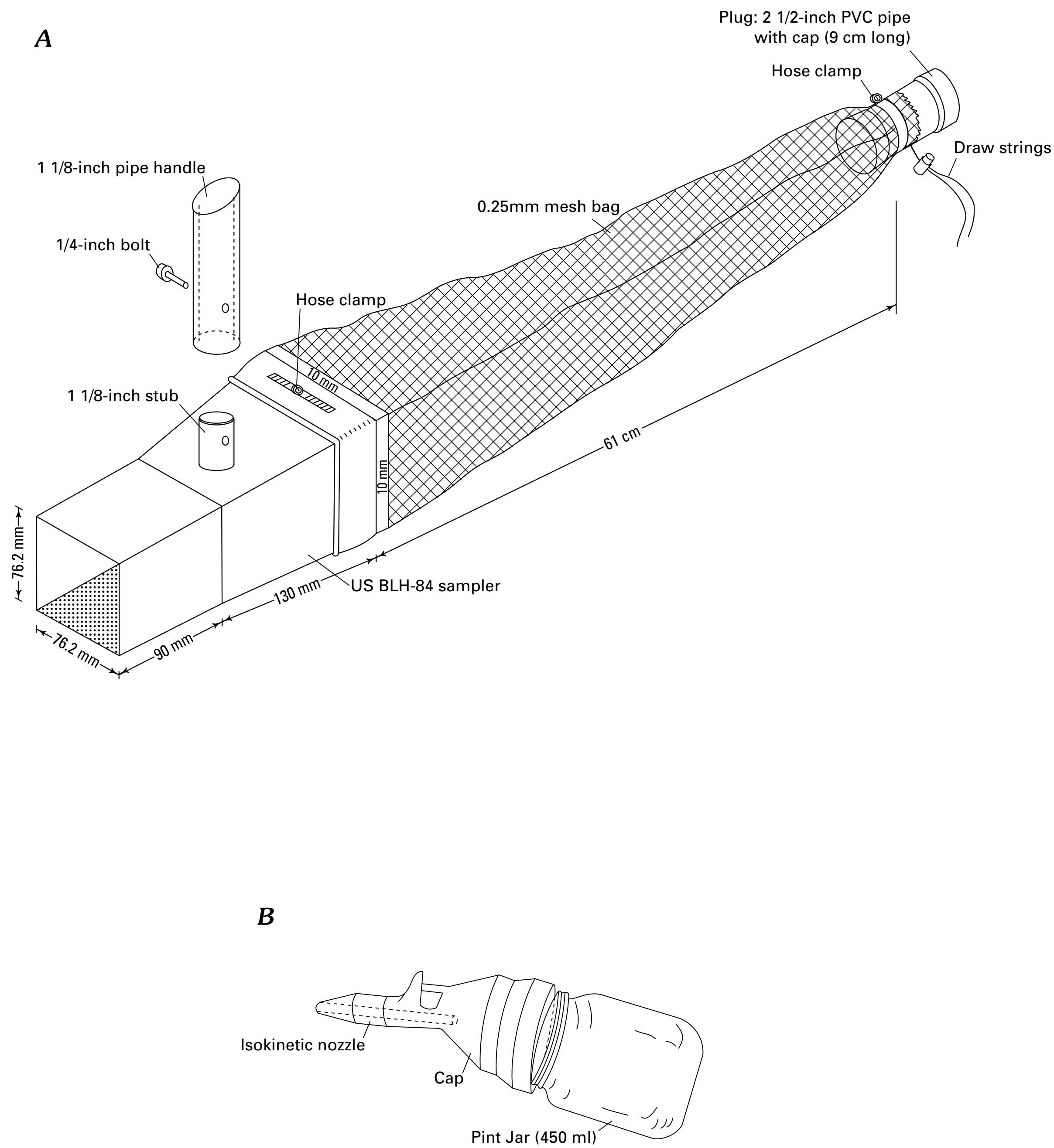


Figure 6.1. Sediment samplers. A. Bed-load sampler US BLH-84. Sediment is removed from the mesh bag by loosening the hose clamp at the end with the plug and removing the plug. Clear water can be poured through the sampler to wash out the sediment. B. Suspended sampler with an isokinetic nozzle.

Because the mesh size of the bed-load sampler was less than the diameter of the isokinetic nozzle, the bed-load sample contained some suspended load. The diameter, D^*, of a particle with a fall velocity equal to the shear velocity, u^*, was used to separate the suspended load from the bed load for each sample. Shear velocity is given by

$$u^* = \sqrt{ghS}, \qquad \textbf{eq. 6.2}$$

where g is the acceleration of gravity, h is the mean depth, and S is the water surface slope. Adjusted bed loads and suspended loads are listed in tables 6.5 and 6.6. One discharge measurement was made between replicates 2 and 3 using a Price AA current meter or surface floats if the water depth was too shallow for the current meter (tables 3.1, 3.2, 6.3, and 6.4).

Thresholds of Motion

Critical shear stress for the largest particles moving as bed load and the settling velocity for the largest particles in suspension were determined for sediment samples collected in Buffalo and Spring Creeks. The median diameter, D_b, of the largest size-class (≤5 percent of the total sample) in the US BLH-84 sampler was assumed to represent the particles just beginning to move as bed load. Because bed forms and bars were not present during sample collection the form drag was assumed to be zero, and thus, the critical shear stress for the initiation of motion was set equal to the total bed shear stress measured during the sample collection (tables 6.7 and 6.8). The settling velocity of the maximum particle size in suspension, D_s, was calculated by using the fourth-order polynomial equation given by Dietrich (1982), with a sediment density, $\rho_s = 2{,}650$ kg/m^3, and a kinematic viscosity, $\nu = 0.0116$ cm^2/s for 15^{o}C.

Indirect Measurements

Indirect measurements were used to determine sediment volume and discharge during flash floods when it was too dangerous to sample sediment or to measure water discharge directly. Sediment volumes transported by these flash floods were deposited in the Spring Creek study reach. This reach expands from 8 m wide at the upper end near the gage to 60 m wide at the mouth and acts as a sediment trap. The flood hydrograph was modeled using a linear reservoir model (Nash, 1958) with n=3 and K ranging from 3.5-10.5 minutes. The predicted hydrograph was constrained by the measured peak discharge and the restriction that the total mass or volume of water must be conserved at the Spring Creek gage site. The South Platte gage site operated by the state of Colorado on the South Platte River at South Platte, Colorado, served as the alternate gage if the Spring Creek gage malfunctioned. Time-averaged discharge was the volume of water divided by the duration of the flash flood. Time-averaged depth (column 2, table 6.9) was then determined from the time-averaged discharge and the critical-flow model applied at the Spring Creek gage site using the measured geometry of the site (table 3.5). The change in the sediment volumes was calculated from the channel surveys (described in section 5) for seven flash floods (table 6.9) and divided by the duration of the flash flood (table 6.9) to estimate the total sediment discharge during a flash flood (table 6.9). Maximum particle sizes, D_b and D_s (table 6.9), moving as bed load and in suspension, were used with the bed material particle-size distribution for Spring Creek (table 6.1, fig. 6.2, and Appendix 12) to determine the proportion of the bed material moving as bed load and as suspended load (table 6.9). These sediment discharges were certainly a minimum estimate, as some sediment was transported down the South Platte River; however, field observations indicate this was probably much smaller than the volume of sediment deposited in the study reach. Peak discharges were determined by high-water marks and the slope-area method (Dalrymple and Benson, 1967). Buffalo Creek was not modeled by this method because most of the volume was transported directly into the North Fork of the South Platte River and very little was stored within the study reach.

Results

Bed Material

Bed material deposited in Buffalo Creek, after the fire and erosional events in 1996, was finer than in Spring Creek. The predominant size class was 2-4 mm in Buffalo Creek and 4-8 mm in Spring Creek (table 6.1, fig. 6.2). Spring Creek had a definite bimodal distribution that was the result of larger cobbles and boulders being sapped from the granite outcrops along the channel sides. These formed boulder bars in the main channel of Spring Creek that occupied about 8 percent of the surface area as viewed on aerial photographs. The bed material was the Pikes Peak granite, which typically weathers into grüs with roughly cubical shapes as illustrated by the Cory shape factor. The distribution of shape factors for one size class (11.3 to 16 mm) was approximately normal (fig. 6.3), with the mean (0.67 mm) almost equal to the median value (0.66 mm).

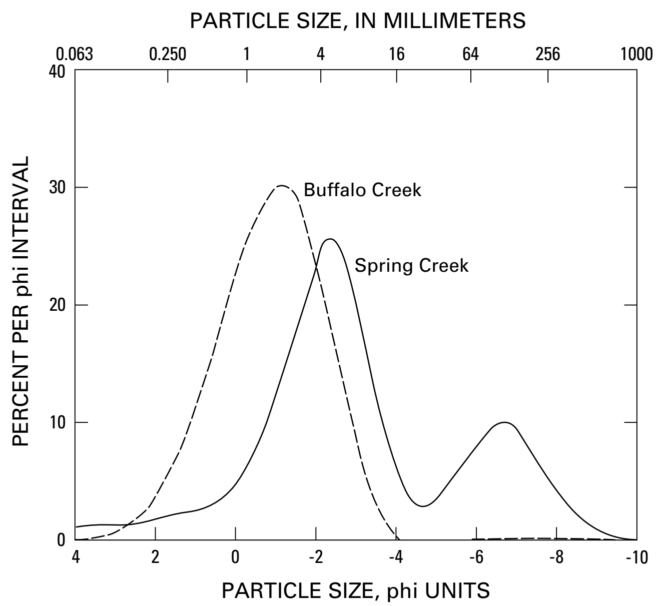


Figure 6.2. Comparison of the particle-size distribution of bed material in Buffalo and Spring Creeks. The second peak on the Spring Creek curve represents large particles sapped from the exposed bedrock along the sides of the channels.

The median size (D_{50}) of the surficial bed material in Spring Creek increases from the headwaters to the mouth. The median size was 1.3 and 1.5 mm in two headwater tributaries (6,260 m upstream from the mouth), and the median size increased to 4.3 mm at the mouth (table 6.2). The degree of sorting indicated by σ is essentially constant (3.0 ±0.3) but is relatively large, which indicates a wide range of sizes. Downstream fining of sediment is generally the rule and has been attributed to abrasion (Shaw and Kellerhals, 1982), selective transport of finer grains (Paola and Seal, 1995), and finer input by tributaries downstream (Pizzuto, 1995). The material in this system has mixed grain sizes, shapes that roll easily, and the relative roughness (bed particle diameters divided by water depth) is much greater than the relative roughness in perennial rivers, where most sediment transport theory has been developed. Particle-size analysis of bed-load measurements discussed below indicate that larger particles are preferentially transported in this system, which could explain the downstream coarsening of bed material.

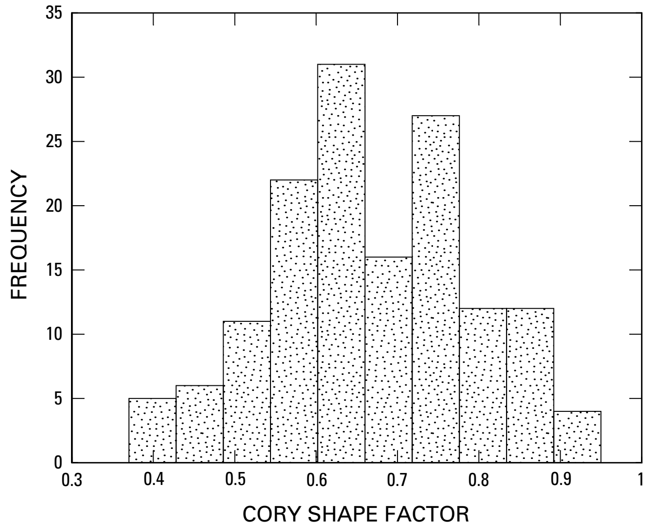


Figure 6.3. Distribution of particle shapes for the 11.3-16.0 mm size class of bed load in Spring Creek. Cory shape factor is defined in the text.

Total Load Rating Curves

Sediment transport rates increased after the wildfire. Total transport rates (bed load and suspended load) were available for Buffalo Creek before the wildfire (fig. 6.4) but not for Spring Creek. After the wildfire, the measured total transport rate (table 6.6) in Buffalo Creek indicated about a 60-fold increase at 0.5 m^3/s, and a 20-fold increase at 1.0 m^3/s (fig. 6.4). Without pre-fire data for Spring Creek, the absolute increase is unknown, but the total sediment transport rate in Spring Creek (tables 6.5 and 6.9) after the wildfire was about 5-10 times the post-fire transport rate in Buffalo Creek. Regression equations for total sediment transport rate, Q_s, and water discharge, Q_w, in Buffalo and Spring Creeks are

$$Q_s = 23Q_w^{1.5}, \ r^2 = 0.89 \qquad \textbf{eq. 6.3}$$

$$Q_s = 23Q_w^{1.3}, \quad r^2 = 0.96 \qquad \textbf{eq. 6.4}$$

The outliers for the Buffalo Creek sediment-rating curve (shown as solid circles in fig. 6.4) are measurements made after most of the sediment in the channel had been evacuated in July 1998 and May 2000 and the channel resembled pre-fire conditions. These outliers agree with the set of pre-fire, total-load measurements made in 1985 in Buffalo Creek (+ symbols in fig. 6.4) when the bed-load:suspended-load ratio averaged 10±3.4 (Williams and Rosgen, 1989) for this relatively clear mountain trout stream. After the fire in Buffalo Creek, the bed-load:suspended-load ratio was less and averaged 6.1±2.8 indicating that much more fine material was available for transport. For Spring Creek, the ratio was greater and more variable (14±16).

Bed-load transport rates (kg/s), when normalized by water discharges (expressed as mass, kg/s, rather than as a volume, m^3/s), give a dimensionless sediment transport efficiency. The effi-

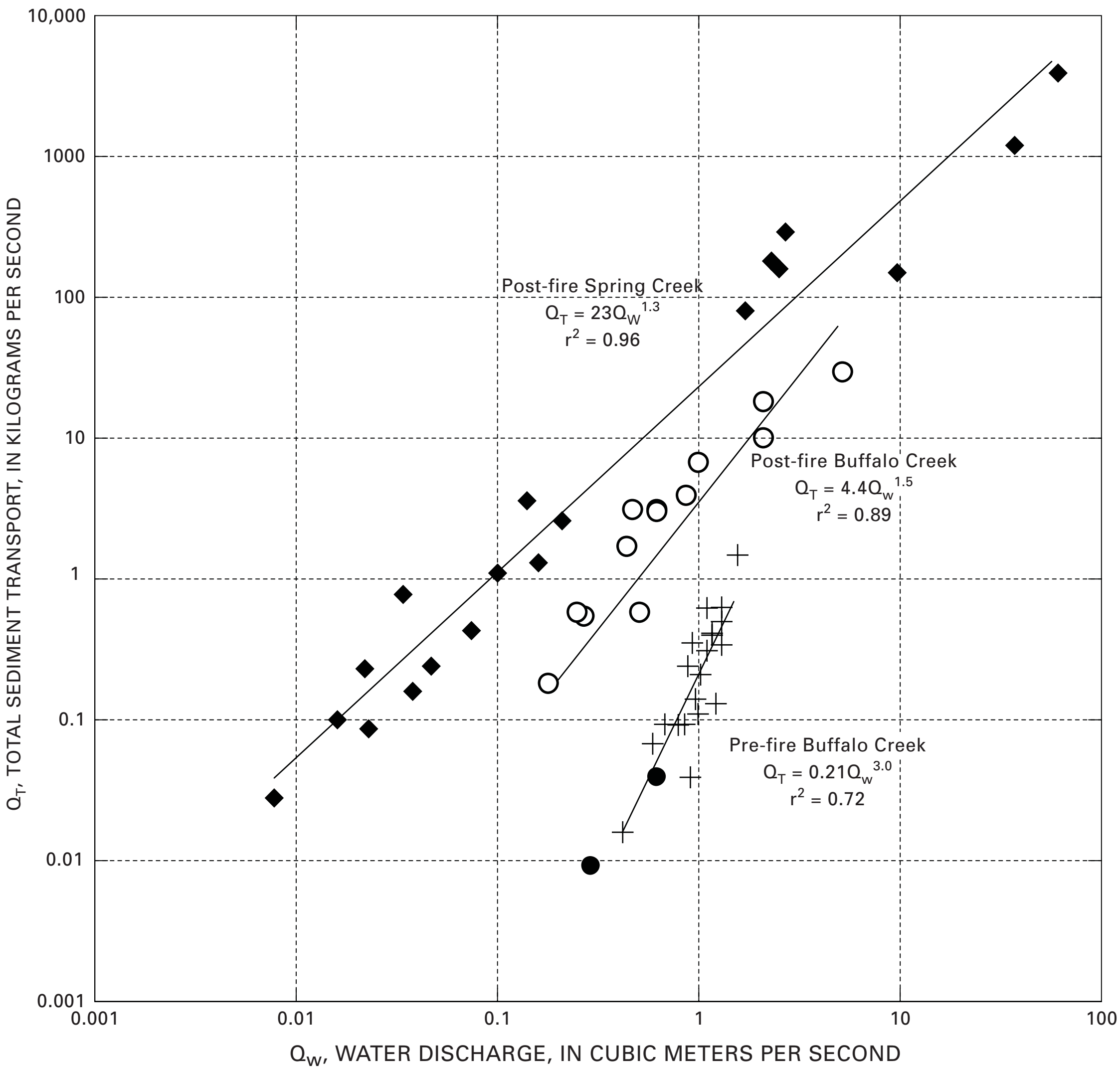


Figure 6.4. Total sediment transport as a function of water discharge in Buffalo and Spring Creeks. The two solid circles represent samples collected in Buffalo Creek after the wildfire when the channel had been flushed of the sand and fine gravel.

ciency of bed-load transport for these two streams increased after the wildfire, in response to the increased sediment supply. Many rivers, ranging in size from the low-gradient Amazon to high-gradient mountain streams, generally have efficiencies in the range of 0.0001 to 0.1 percent and are usually slope limited in the case of the Amazon or supply limited in the case of mountain streams (table 6.10). Spring Creek had efficiencies that ranged from 0.34 to 2.3 percent after the wildfire, while in Buffalo Creek they ranged from 0.0019 to 0.76 percent, which represented an approximate 10-fold increase from pre-fire efficiencies. Relatively high efficiencies (0.0077 to 0.17 percent, based on data reported by Williams and Rosgen, 1989), were calculated for the Toutle River where the sediment supply was increased as a result of the eruption of Mount St. Helens in 1980. Some of the highest efficiencies (7.5 percent, based on data reported by Lekach and Schick, 1983; Lekach and others, 1992) occur in the desert, where unsteady flow or flash floods are also the dominant transport process. The relatively high bed-load transport efficiency is probably a result of steep channel slopes, increased sediment supply, and the mixed grain sizes in the bed material.

Initiation of Motion for Bed Load

Critical thresholds for bed-load movement in mixed-grain-size beds were very different than those for uniform grains. In general, particles less than about 11 mm in diameter were always moving on the bed of Buffalo and Spring Creeks so that the critical shear stress was only determined for larger particles. It ranged from 5.4 N/m^2 for particle diameters of 11 mm to 470 N/m^2 for a boulder-size particle (diameter of about 1000 mm). The latter value is similar to the critical shear stress (480 N/m^2) extrapolated for a 1000 mm particle reported by Leopold and others (1964, figure 6-11, p. 170). Non-dimensional shear stress, τ^*, which is given by

$$\tau^* = \tau/(g(\rho_s - \rho)D_b) \qquad \textbf{eq. 6.5}$$

where τ is the bed shear stress, ρ_s and ρ are the density of the sediment and water, and D_b is the median diameter of the largest size-class transported as bed load. For the conditions of a mixed grain-size bed, the non-dimensional shear stress decreases with an increase in the relative roughness, D_b/h (fig. 6.5). These relations for the critical shear stress, τ^*_c, in Buffalo and Spring Creeks are

$$\tau^*_c = 0.0059(D_b/h)^{-1.2} \qquad r^2 = 0.86\,, \qquad \textbf{eq. 6.6}$$

and

$$\tau^*_c = 10.020(D_b/h)^{-0.88} \qquad r^2 = 0.80\,. \qquad \textbf{eq. 6.7}$$

The data point shown as an open circle (fig. 6.5) corresponds to low shear stress conditions and when very little sand was on the bed of Buffalo Creek such that a bed of mixed grain sizes was not present (4 June 2000). This point was not included in the regression above. In contrast, data reported by Suszka (1991) for several laboratory experiments, done with a bed of uniform grains indicate that the non-dimensional shear stress increases with increase in the relative roughness, D_b/h

$$\tau^*_c = 0.092(D_b/h)^{0.32}\,, \qquad r^2 = 0.87\,. \qquad \textbf{eq. 6.8}$$

That is, the non-dimension shear stress increases with an increase in relative roughness (fig. 6.5). This result for uniform grains was thought to be caused by the increase in eddies (Nakagawa and others, 1991; Suszka, 1991; and Tsujimoto, 1991) being shed near the bed as the relative roughness increased. Thus, the vertical shear and Reynolds stresses decreased and more of the total shear stress is required to move the particle. At present, for beds with mixed grain sizes, the explanation is not completely understood, but it is probably a result of the decrease in the friction or pocket angle for large particles on a bed of smaller particles, and the corresponding increased exposure of large particles to the shear. This increase in the transport of larger particles in the presence of smaller particles was first noted by Gilbert (1914) in his flume experiments with sediment mixtures.

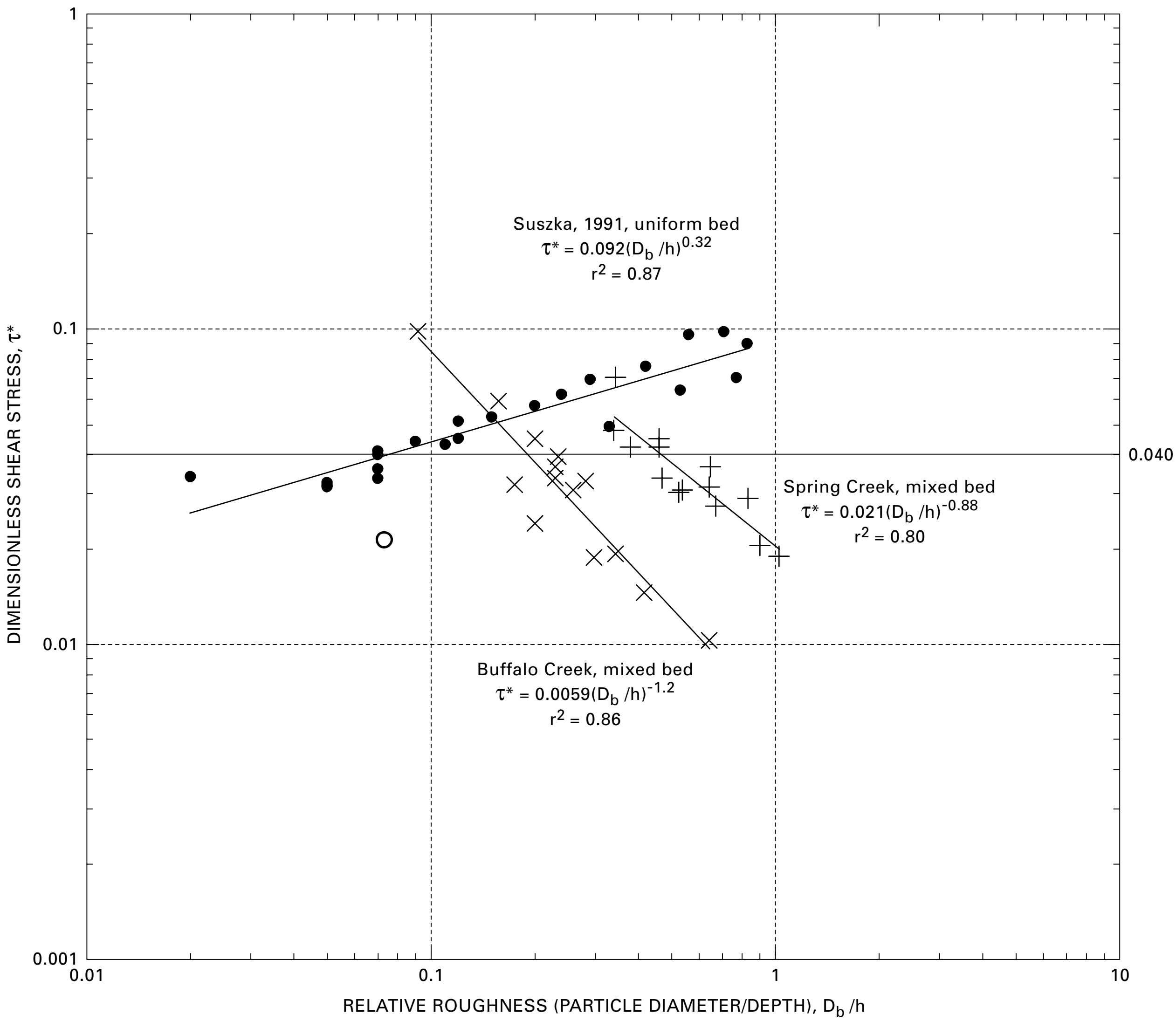


Figure 6.5. Initiation of motion of bed material as a function of relative roughness. Samples were collected in Buffalo Creek (x's) and Spring Creek (+'s). Dimensionless shear stress is defined in the text. The data for uniform bed material were measured in the laboratory and are shown as solid circles. The open circle corresponds to conditions in Buffalo Creek of low shear stress and almost no sand on the bed such that a bed of mixed grain sizes was not present. This point was not included in the regression

Mobility of Coarse Sediment

The particle-size data for the bed-load samples (table 6.3) were analyzed to investigate the mobility of coarse particles (> 4 mm) in Spring Creek. For each size class, the ratio of the percent of sediment transported to the percent of sediment available for transport was calculated (table 6.11). The percent available for transport was determined by recalculating the particle-size distribution of the bed material (table 6.1) when those sizes which did not move were excluded. The ratio for the median-size class (4-8 mm) was about 0.85 for Spring Creek and 0.95 for Buffalo Creek. The data suggest a maximum for particle sizes larger (about 8-16 mm) than the 4-8 mm size class (fig. 6.6). The maximum ratio was for the 16-32 mm size class and was associated with the maximum bed shear stress (28 N/m^2). In general, the maximum ratio decreased and the corresponding particle size decreased as the bed shear stress decreased; however, there were exceptions, like 28 June 1997. These data seem to indicate that particles coarser than the median grain size may be preferentially transported in Spring Creek. In Buffalo Creek, the sediment coarser than the median size class (2-4 mm) generally did not appear to be preferentially transported (table 6.12) because the increase in sediment transport was usually less than 20 percent (a typical error for sediment measurements) of the sediment available in the bed. This may be because the relative roughness and bed slope are generally less than in Spring Creek or because of the difference in the sediment-size distribution of the bed material (fig. 6.2).

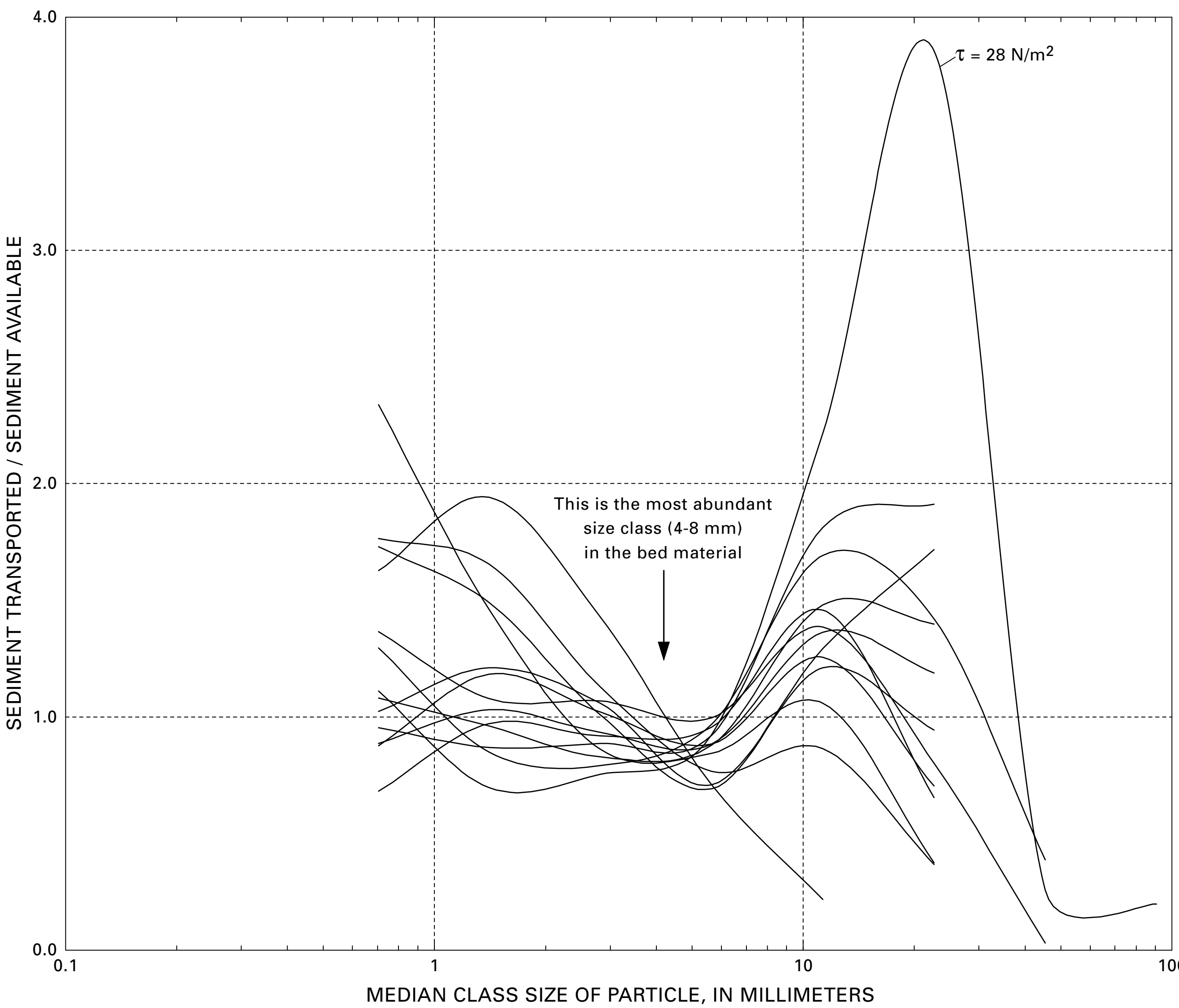


Figure 6.6. Relative mobility of coarse sediment in Spring Creek. Sediment available for transport is based on data in table 6.1 and figure 6.2. Sediment transported is listed in table 6.3.

Transport Regimes

Three different transport regimes (uniform, discontinuous, and unsteady) existed at different times and for varying lengths of time in Spring Creek (Moody, 2001). The uniform regime had steady and spatially continuous flow and both non-cohesive and cohesive (frozen) bed conditions, depending upon the time of year. This relatively uniform transport regime existed when the water discharge ranged from 0.074-0.21 m^3/s in the early spring and during the summer. Streamflow was the result of snowmelt and elevated baseflow from summer rains percolating into the highly fractured Pikes Peak granite. The discontinuous regime occurred with very low discharge (<0.01 m^3/s) flowing over the non-cohesive surficial sediment. This regime frequently occurred during the summer. Streamflow was discontinuous, with flow disappearing into the bed, depositing bed load, and leaving a convex cross-channel profile. This type of deposit had a stoss slope slightly less than the slope of the bed in the downstream direction and a lee slope much greater than the bed slope. Downstream from the base of the lee slope the water reappeared, eroding a channel. The unsteady regime existed for a relatively short time when the discharge changed from 0.02-0.20 m^3/s to 20-180 m^3/s during flash floods. In Spring Creek, flash floods accounted for 67 percent of the sediment transported from the watershed and steady-flow conditions accounted for 33 percent, while in Buffalo Creek flash floods accounted for 15 percent and steady-flow conditions accounted for 85 percent of the sediment transported.

Bed-Load and Suspended-Load Rating Curves

The total sediment rating curve (fig. 6.4) was separated into two rating curves for bed load and suspended load. The direct and indirect measurements of bed-load and suspended-load transport per unit width were combined to produce sediment rating curves for Spring Creek (fig. 6.7) but only direct measurements were used for Buffalo Creek (fig. 6.8). Bed-load transport per unit width in both Spring and Buffalo Creeks was greater than the suspended-load transport. At very high unit discharges, greater than those sampled, extrapolation of the data suggest that the suspended load in Spring Creek may exceed the bed load.

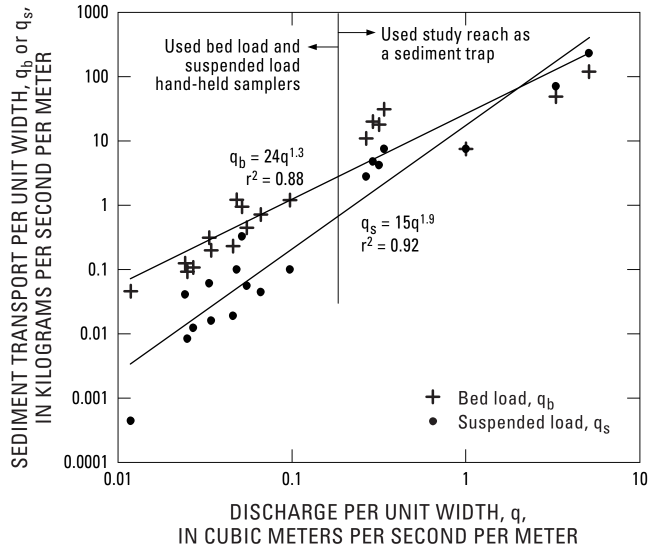


Figure 6.7. Bed-load and suspended-load transport per unit width as a function of water discharge per unit width in Spring Creek. Bed-load measurements, q_b, are shown as plus symbols and suspended-load measurements, q_s, are shown as solid circles.

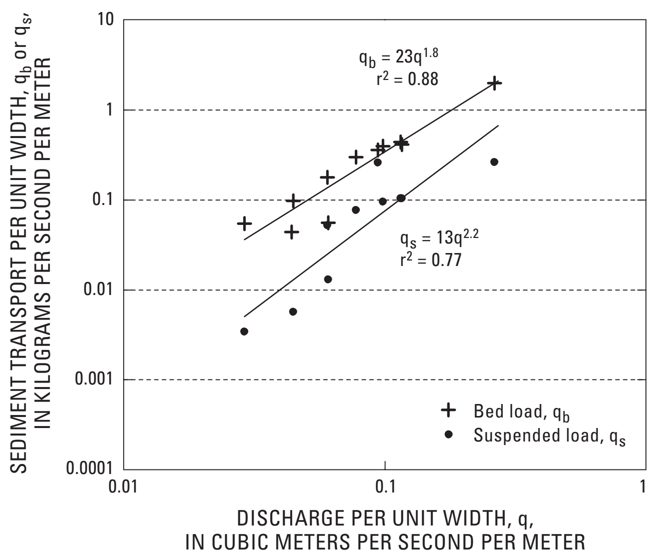


Figure 6.8 Bed-load and suspended-load transport per unit width as a function of water discharge per unit width in Buffalo Creek. Bed-load measurements, q_b, are shown as plus symbols and suspended-load measurements, q_s, are shown as solid circles.

Summary

The bed material in Buffalo and Spring Creeks after the wildfire and floods in 1996 was an unsorted mixture ranging in size from silt to boulders, but with median diameters of about 3 and 6 mm, respectively. Spring Creek had a second mode of rocks and boulders sapped from the side walls of the channels. Bed material in the Spring Creek watershed coarsened slightly in the downstream direction. Based on the data for Buffalo Creek, the total sediment transport after the wildfire was about 10 times greater than before the wildfire, and the transport in Spring Creek after the wildfire was 5-10 times greater than transport in Buffalo Creek after the wildfire. Field measurements of the dimensionless critical shear stress, τ^*_c, for the initiation of motion in these mixed-grain size systems indicate τ^* decreases with an increase in relative roughness, contrary to laboratory results for uniform grain sizes. Data collected in Spring Creek indicate that the coarse grain sizes (>4 mm) are preferentially transported, which is supported by the observation that the bed material coarsens downstream.

Table 6.1. Summary of the particle-size distribution of surficial bed material in Spring Creek and Buffalo Creek after the wildfire and floods in 1996

[mm, millimeter; kg, kilogram; Tributary 2.25 is 2.25 miles, Tributary 3.1 is 3.1 miles, and Tributary 3.11 is 3.11 miles from the intersection of Forest Road 550 and Forest Road 543; C.I. = confidence limits]

Site	Percent of total													Comment
	< 0.063 mm	0.063 - 0.125 mm	0.125 - 0.250 mm	0.250 - 0.500 mm	0.500 -1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	64-128 mm	> 128 mm	
Spring Creek														
Mouth	1.6	1.3	1.2	2.3	3.3	7.5	17.2	26.9	10.9	2.9	6.6	10.3	8.0	A single 53 kg surficial sample was collected at the mouth and used to determine the distribution of particle sizes less than 128 mm. Aerial mapping was used to determine the amount of particles greater than 128 mm.
Buffalo Creek														
Mouth	0.2	1.3	4.5	9.5	11.3	17.8	22.5	21.7	8.1	1.6	1.3	0.0		A single 10 kg surficial sample was collected about 100 m upstream from the mouth.
Tributaries to Buffalo Creek														
Tributary 2.25	0.1	0.4	1.7	8.1	23.7	29.7	20.1	16.2	0.0	0.0	0.0	0.0		A channel sample was collected about 40 m upstream from mouth.
Tributary 2.25	0.1	0.3	1.3	5.7	18.7	34.6	32.3	7.0	0.0	0.0	0.0	0.0		A channel sample was collected about 320 m upstream from mouth.
Tributary 2.25	0.1	0.4	1.3	3.6	11.5	28.1	40.4	14.4	0.2	0.0	0.0	0.0		A channel sample was collected about 440 m upstream from mouth.
Tributary 3.1	0.1	0.2	0.6	2.3	6.5	17.4	32.5	32.1	8.2	0.0	0.0	0.0		A channel sample was collected about 100 m upstream from mouth.
Tributary 3.11	0.2	0.8	4.0	11.6	22.2	24.3	29.7	6.6	0.5	0.0	0.0	0.0		Collected sample from an alluvial fan at the mouth next to Forest Road 543.
Mean	0.1	0.4	1.8	6.3	16.5	26.8	31.0	15.3	1.8	0.0	0.0	0.0		
95 % C.I.	0.1	0.3	1.7	4.7	8.8	8.8	10.4	13.0	4.2	0.0	0.0	0.0		

Table 6.2. Summary of the particle-size distribution of surficial bed material in the Spring Creek channel and one of its tributaries after the wildfire and floods in 1996 and 1997

[mm, millimeter; m, meter; medium size (1-3 kilogram) samples were collected 24 April 1998; D_{84} = 84 percent are finer than this diameter; D_{50} = 50 percent are finer than this diameter; D_{16} = 16 percent are finer than this diameter; $\sigma = \sqrt{D_{84}/D_{16}}$]

Distance upstream from the mouth (m)	Percent of total											D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	σ
	< 0.063 mm	0.063 - 0.125 mm	0.125 - 0.250 mm	0.250 - 0.500 mm	0.500 -1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm				
Main channel of Spring Creek and up a tributary with its mouth 5,060 m upstream from the mouth of Spring Creek															
6,260.[a]	1.1	1.5	4.1	13.8	21.3	16.5	23.8	16.7	1.2	0.0	0.0	0.42	1.5	4.5	3.3
6,260.[b]	0.4	0.9	2.7	11.1	23.6	34.8	19.2	6.5	0.7	0.0	0.0	0.52	1.3	3.1	2.4
5,060	0.9	0.8	2.1	6.4	14.8	20.2	20.3	18.1	11.0	5.3	0.0	0.70	2.5	8.0	3.4
4,850	2.8	1.6	2.8	6.2	11.9	19.9	32.3	20.1	2.4	0.0	0.0	0.55	2.3	5.3	3.1
4,200	2.4	2.3	3.1	4.1	7.5	15.0	25.3	27.7	12.1	0.4	0.0	0.77	3.2	7.5	3.1
3,470	1.0	0.8	1.2	3.4	6.5	11.0	20.1	33.6	21.3	1.0	0.0	1.3	4.7	10.4	2.8
2,600	1.1	1.0	1.2	2.2	6.1	14.0	23.0	29.2	19.7	2.6	0.0	1.3	4.2	10.6	2.9
0[c]	1.4	0.9	1.5	3.5	6.5	12.8	21.4	28.9	17.1	6.2	0.0	1.2	4.3	11.3	3.1
Tributary begins 2,180 m upstream from the mouth of Spring Creek															
900	1.9	2.4	6.0	14.1	18.9	24.4	25.8	5.9	0.2	0.3	0.0	0.35	1.3	3.3	3.1
0	1.3	1.1	1.4	4.5	11.5	21.9	30.4	20.7	5.8	1.2	0.0	0.83	2.5	6.3	2.8

[a]Sample was from a different tributary than the sample below.

[b]Sample was from a different tributary than the sample above.

[c]Sample was collected on 12 December 1996.

Table 6.3. Summary of the particle-size distribution of replicate samples of bed and suspended load collected near the mouth of Spring Creek, 1997-2000

[This table contains raw values; bed load is all the sediment that is collected in a USBLH-84 sampler, and suspended load is all the sediment collected by the pint-jar sampler with an isokinetic nozzle; dry masses have been used in calculating transport rates and concentrations; some sizes of bed load may have been in suspension depending upon the water discharge; mm, millimeter; kg/s, kilogram per second; mg/L, milligram per liter; m^3/s, cubic meter per second; *, some organic material]

Replicate	Bed load (percent of total)									Suspended load (percent of total)						
	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	Transport rate (kg/s)	< 0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	Concentration (mg/L)
Wooden Parshall flume at the mouth of Spring Creek, 28 June 1997, 0.016 m^3/s																
1	1.1	5.1	16.9	26.9	31.6	16.0	2.3	0	0.10	17.2	60.5	17.8	*4.5	0	0	780
2	5.2	11.1	18.5	23.1	26.1	15.1	0.9	0	0.078	13.9	52.4	24.9	*8.8	0	0	2200
3	1.4	6.5	16.0	26.8	31.8	14.9	2.4	0	0.076			no replicate was collected				
4	2.9	10.3	18.9	33.1	27.1	7.3	0.4	0	0.056			no replicate was collected				
Wooden Parshall flume at the mouth of Spring Creek, 2 July 1997, 0.0078 m^3/s																
1	4.1	5.8	14.6	27.6	29.9	13.2	4.7	0	0.015	51.0	26.6	15.6	6.8	0	0	34
2	0.2	0.8	8.1	24.1	37.3	24.3	5.0	0	0.021			no replicate was collected				
3	0.5	2.1	9.4	22.9	37.2	25.8	2.1	0	0.030	35.6	37.3	19.7	4.1	3.3	0	33
4	1.0	5.4	16.1	24.7	31.1	19.7	2.0	0	0.039			no replicate was collected				
5	2.0	6.6	15.3	26.2	34.4	14.9	0.8	0	0.033			no replicate was collected				
At gaging site on Spring Creek, 2 July 1997, $<0.1\ m^3/s$																
1	12.5	13.0	12.9	15.7	23.0	23.5	0	0	0.0010				no samples			
2	8.2	11.7	17.5	26.4	18.9	17.3	0	0	0.0013				no samples			
Wooden Parshall flume at the mouth of Spring Creek, 11 July 1997, 0.0036 m^3/s																
1	6.3	6.3	21.9	50.0	15.6	0	0	0	0.000080	75.6	13.5	6.6	*4.4	0	0	38
2	1.8	8.3	22.9	28.4	38.5	0	0	0	0.00027	64.5	19.7	7.0	4.2	4.7	0	49
3	2.6	9.0	19.2	29.5	29.5	10.3	0	0	0.00020	77.9	10.9	7.3	3.0	0.9	0	107
Wooden Parshall flume at the mouth of Spring Creek, 3 August 1997, 0.022 m^3/s																
1	3.3	2.9	5.2	16.4	42.0	26.7	3.5	0	0.10	45.7	10.1	28.3	11.5	4.4	0	1700
2	4.8	9.0	11.5	23.3	28.9	19.5	3.1	0	0.24	51.6	18.2	20.0	5.4	4.8	0	1400
3	2.7	6.6	11.3	25.1	34.9	15.1	3.4	0.9	0.26	52.3	14.5	27.2	2.9	3.1	0	1900
4	2.5	4.6	13.5	29.5	31.7	16.2	1.9	0	0.16	51.4	16.6	17.1	9.8	5.1	0	1200
Wooden Parshall flume at the mouth of Spring Creek, 5 August 1997, 0.034 m^3/s																
1	3.9	7.0	9.8	17.7	25.8	25.9	9.9	0	0.56	45.6	11.7	35.2	4.9	2.6	0	5500
2	3.5	3.8	4.1	10.9	24.9	31.0	19.0	2.8	0.42	56.3	19.1	13.8	6.7	*3.0	*1.0	4800
3	1.2	1.0	2.1	13.7	33.8	26.2	9.9	3.1[a]	0.62	48.0	14.3	26.5	6.6	*3.5	*1.1	6800
4	3.4	4.8	7.6	16.4	27.8	26.4	11.9	1.7	0.74	48.2	31.5	12.7	*4.2	*2.1	*1.2	6000
Mouth of Spring Creek, 15 September 1997, 0.040 m^3/s																
1	5.2	7.2	9.1	17.1	25.6	21.7	14.1	0	0.12	47.3	19.1	16.0	12.6	5.0	0	330
2	1.4	3.7	15.9	28.1	25.4	20.5	5.0	0	0.14	60.5	18.0	13.4	4.7	3.3	0	290
3	1.6	2.4	8.1	28.5	31.7	22.1	5.6	0	0.14	60.0	22.6	10.5	4.3	2.6	0.2	370
4	2.6	5.8	18.3	29.3	25.2	15.4	3.5	0	0.19	39.7	18.5	25.6	10.8	5.4	0	470

Table 6.3. (Continued) Summary of the particle-size distribution of replicate samples of bed and suspended load collected near the mouth of Spring Creek, 1997-2000

Replicate	Bed load (percent of total)									Suspended load (percent of total)						
	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	Trans-port rate (kg/s)	< 0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	Concen-tration (mg/L)
Mouth of Spring Creek, 8 October 1997, 0.023 m^3/s																
1	0.6	3.8	16.5	31.4	29.3	14.9	3.5	0	0.092	not available						
2	8.6	9.1	16.1	22.7	22.9	17.4	3.3	0	0.029	51.8	26.9	14.9	5.0	1.3	0	180
3	5.0	11.0	14.5	20.1	27.0	19.8	2.6	0	0.14	51.8	28.8	11.3	3.9	4.1	0	180
4	4.0	7.8	15.0	22.1	24.0	21.2	5.8	0	0.063	26.4	13.4	29.0	22.4	8.8	0	310
Mouth of Spring Creek, 21 May 1998, 0.16 m^3/s																
1	3.7	6.8	9.4	14.4	27.9	21.3	6.7	9.9	0.78	33.9	12.5	13.6	29.7	8.6	1.7	1400
2	4.2	4.8	6.4	18.8	33.6	25.1	3.9	3.1	1.15	30.0	16.5	24.5	20.0	7.7	1.2	1400
3	3.4	3.7	5.2	15.5	39.4	26.8	6.0	0	1.43	55.8	17.1	15.7	7.4	3.3	0.7	580
4	2.5	6.6	11.6	21.0	32.5	21.4	4.5	0	1.39	50.7	17.4	14.0	10.4	5.6	1.9	550
Mouth of Spring Creek, 26 June 1998, 0.074 m^3/s																
1	2.1	5.0	10.3	18.1	38.2	25.3	1.0	0	0.38	31.7	12.1	13.8	26.2	11.5	4.7	480
2	1.1	1.8	12.0	22.5	36.0	22.8	3.8	0	0.34	34.3	15.1	16.0	22.9	9.8	1.8	620
3	1.3	1.6	7.0	22.0	38.7	25.1	4.4	0	0.39	36.6	15.4	18.7	17.4	10.9	0.9	380
4	2.7	4.4	12.3	27.6	33.9	17.5	1.6	0	0.46	40.9	16.4	16.2	17.3	3.6	5.6	510
Mouth of Spring Creek, 5 August 1998, 0.14 m^3/s																
1	3.8	7.0	13.0	17.5	26.9	25.8	6.0	0	2.7	40.3	17.5	10.7	15.8	10.0	5.6	1300
2	1.1	2.4	7.8	17.2	35.6	27.2	8.7	0	3.0	39.6	19.0	13.7	14.9	9.1	3.7	1500
3	1.0	3.0	10.9	27.1	35.4	17.9	4.8	0	3.2	41.1	19.6	11.0	11.7	10.4	6.2	2100
4	4.3	7.8	9.1	19.0	35.8	20.5	3.5	0	5.0	28.9	13.0	11.9	15.0	20.7	10.5	2500
Mouth of Spring Creek, 15 May 1999, 0.100 m^3/s																
1	1.5	3.1	9.1	16.6	36.2	27.2	6.3	0	0.54	37.7	17.7	17.6	17.0	7.0	3.0	690
2	2.7	6.3	9.1	23.2	34.7	19.5	4.5	0	1.6	28.4	11.2	21.9	24.7	13.0	0.7	770
3	1.8	4.6	13.6	24.6	30.3	19.5	5.6	0	2.0	38.0	19.0	18.7	16.1	6.4	1.7	560
4	0.9	2.7	12.4	27.3	34.6	18.7	3.3	0	1.6	23.5	21.3	29.9	16.4	6.7	2.2	510
Mouth of Spring Creek, 26 May 1999, 0.21 m^3/s																
1	0.6	0.2	2.2	15.7	34.7	34.5	12.0	0	1.6	35.0	27.1	24.4	11.2	2.0	0.2	810
2	1.0	3.0	10.0	19.8	33.6	25.4	7.1	0	2.8	38.4	19.8	17.7	12.8	7.7	3.6	920
3	6.1	10.3	11.6	12.2	28.3	26.0	3.7	1.8	2.5	42.5	18.0	18.9	13.5	5.9	1.2	810
4	1.2	2.8	10.0	31.4	31.9	16.6	6.0	0	2.7	30.5	19.4	18.3	22.9	8.7	0.2	1100
Mouth of Spring Creek, 2 May 2000, 0.047m^3/s																
1	2.5	1.8	2.3	10.6	49.3	29.5	4.0	0	0.078	30.5	23.7	17.9	9.3	6.6	12.0	230
2	6.4	13.7	18.5	26.6	24.9	9.5	0.4	0	0.33	18.0	13.5	23.8	26.6	18.1	0.0	400
3	3.4	12.3	19.7	22.1	27.6	13.8	1.1	0	0.27	41.4	15.9	11.0	8.9	18.2	4.6	170
4	5.0	15.2	20.5	23.0	24.4	11.4	0.5	0	0.24	21.2	11.3	21.3	31.1	11.6	3.5	410

[a]9.1percent is in the size class 64-128 mm.

Table 6.4. Summary of the particle-size distribution of replicate samples of bed and suspended load collected near the mouth of Buffalo Creek, 1997-2000

[This table contains raw values; bed load is all the sediment that is collected in a US BLH-84 sampler, and suspended load is all the sediment collected by the pint-jar sampler with an isokinetic nozzle; dry masses have been used in calculating transport rates and concentrations; some sizes of bed load may have been in suspension depending upon the water discharge; mm, millimeter; kg/s, kilogram per second; mg/L, milligram per liter; m^3/s, cubic meter per second; *, some organic material]

	Bed load (percent of total)									Suspended load (percent of total)						
Replicate	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	Transport rate (kg/s)	< 0.063 mm	0.063 - 0.125 mm	0.125 - 0.250 mm	0.250 - 0.500 mm	0.500 -1.00 mm	1-2 mm	Concentration (mg/L)
Mouth of Buffalo Creek, 20 March 1997, 0.18 m^3/s																
1	13.5	16.1	25.8	25.1	16.1	3.4	0	0	0.12	no sample processed						
2	12.3	19.6	26.6	21.3	16.0	4.1	0	0	0.29	no sample processed						
3	17.9	24.8	22.0	18.0	13.5	3.8	0	0	0.13	no sample processed						
Mouth of Buffalo Creek, 1 July 1997, 0.51 m^3/s																
1	17.9	14.1	21.4	20.9	16.7	8.4	0.7	0	0.33	59.7	11.5	20.2	8.6	0	0	150
2	10.8	17.2	24.2	21.6	18.0	7.1	1.2	0	0.34	39.1	12.4	39.1	7.8	1.6	0	260
3	8.8	11.2	18.3	26.2	26.9	8.7	0	0	0.45	41.1	19.6	28.8	7.8	2.6	0	300
4	9.1	9.2	15.8	24.0	30.5	10.6	0.7	0	0.76	41.0	22.1	21.5	12.2	3.3	0	280
Mouth of Buffalo Creek, 14 July 1997, 0.27 m^3/s																
1	6.3	13.0	23.7	27.9	22.3	6.3	0.6	0	0.50	44.8	23.1	21.3	8.4	2.3	0	130
2	8.7	15.1	21.5	25.4	21.5	6.7	1.1	0	0.50	34.8	25.4	26.9	10.6	2.3	0	180
3	6.4	14.1	25.0	26.8	20.0	7.7	0	0	0.44	49.0	23.3	15.2	10.0	2.5	0	120
4	9.3	19.0	21.2	21.4	22.9	6.1	0	0	0.59	43.3	22.6	20.2	11.6	2.3	0	130
480 m upstream from the Mouth of Buffalo Creek, 14 July 1997, 0.25 m^3/s																
1	4.5	12.8	22.3	28.1	25.4	6.6	0.3	0	0.59	40.0	18.4	21.7	15.6	4.4	0	150
2	6.5	13.3	19.3	25.6	25.4	9.2	0.7	0	0.57	37.7	25.2	21.6	10.0	5.5	0	130
3	4.4	13.0	21.5	28.1	25.4	7.0	0.6	0	0.53	33.3	16.9	26.6	17.3	5.8	0	180
4	4.9	9.1	19.3	28.0	27.7	9.0	1.9	0	0.52	35.6	17.3	31.4	10.4	5.2	0	160
Mouth of Buffalo Creek, 19 August 1997, 0.44 m^3/s																
1	9.8	9.0	17.0	25.7	25.0	10.3	1.6	1.6	0.91	31.8	18.1	35.0	12.0	3.2	0	1000
2	9.5	13.3	18.7	23.2	21.4	10.4	3.5	0	1.4	33.6	18.7	33.9	11.6	2.3	0	1200
3	8.5	8.5	20.6	28.2	24.9	8.3	1.0	0	1.5	40.7	23.9	21.3	11.7	2.4	0	840
Mouth of Buffalo Creek, 1 September 1997, 0.47 m^3/s																
1	11.8	12.6	17.9	21.4	24.6	10.0	1.6	0	1.7	44.1	19.0	16.2	16.8	3.9	0	2500
2	8.8	13.6	21.0	25.5	22.3	7.2	1.6	0	2.7	40.0	11.4	34.3	11.3	3.1	0	2700
3	16.1	19.1	21.4	18.4	18.6	5.9	0.5	0	1.6	42.1	22.4	19.3	12.1	4.2	0	2800
4	8.7	11.5	19.4	29.8	23.1	7.5	0.0	0	2.2	39.2	20.7	15.7	14.6	6.7	3.1	3000
Mouth of Buffalo Creek, 3 November 1997, 0.62 m^3/s--morning																
1	9.4	13.7	19.2	23.6	22.3	9.9	1.9	0	3.1	34.6	21.3	32.4	10.0	1.7	0	640
2	7.5	9.7	18.5	27.4	25.2	9.9	1.9	0	2.4	21.7	13.1	45.8	17.1	*2.2	0	750
Mouth of Buffalo Creek, 3 November 1997, 0.62 m^3/s--afternoon																
1	7.9	9.1	15.2	28.7	24.7	12.5	1.9	0	3.1	29.6	20.8	27.8	19.0	*2.7	0	660
2	9.4	16.2	20.8	22.5	20.6	9.7	0.7	0	2.9	24.1	15.5	27.5	26.8	6.0	0.1	980
3	8.6	14.6	23.5	23.8	19.2	8.9	1.3	0	3.9	24.1	20.6	28.2	22.2	*4.9	0	1000
4	9.8	9.1	15.8	25.5	27.7	11.4	0.8	0	3.3	no usable data						

Table 6.4. (Continued) Summary of the particle-size distribution of replicate samples of bed and suspended load collected near the mouth of Buffalo Creek, 1997-2000

Rep-licate	Bed load (percent of total)									Suspended load (percent of total)						
	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	Trans-port rate (kg/s)	< 0.063 mm	0.063 - 0.125 mm	0.125 - 0.250 mm	0.250 - 0.500 mm	0.500 -1.00 mm	1-2 mm	Concen-tration (mg/L)
Mouth of Buffalo Creek, 7 November 1997, 0.87 m^3/s																
1	7.4	10.9	17.0	25.4	28.4	10.9	0.0	0	3.5	22.2	17.6	26.3	23.2	10.8	0	860
2	4.5	7.9	21.2	31.9	25.4	7.9	1.1	0	3.3	26.5	17.1	31.3	18.8	6.3	0	870
3	13.1	15.6	19.5	22.2	20.3	8.7	0.6	0	3.1	22.1	12.2	29.4	23.1	13.3	0	970
4	4.1	7.1	19.2	28.8	30.2	10.4	0.2	0	3.6	21.5	14.8	25.8	25.6	12.3	0	1100
Mouth of Buffalo Creek, 9 May 1998, 2.1 m^3/s																
1	11.9	18.0	21.9	21.8	18.2	7.4	0.7	0	8.9	22.0	16.6	25.8	22.2	7.0	6.5	763
2	8.9	12.9	16.4	21.8	27.8	11.2	0.9	0	7.8	25.6	18.6	24.9	25.6	4.3	1.0	720
3	9.4	13.6	19.2	21.0	24.0	9.6	3.3	0	9.7	24.1	19.0	31.1	18.8	5.0	2.0	670
4	8.8	16.9	22.1	22.3	21.9	7.0	1.0	0	9.4	25.6	16.0	26.3	23.2	7.6	1.3	870
480 m upstream from the Mouth of Buffalo Creek, 9 May 1998, 2.1 m^3/s																
1	6.8	13.9	21.0	24.9	23.2	9.6	0.7	0	17	13.7	11.3	23.5	33.8	12.2	5.4	1100
2	6.7	14.7	23.6	25.1	20.2	7.5	1.0	1.2	18	8.3	7.5	20.4	39.0	20.5	4.3	1600
3	4.7	8.2	17.3	25.9	31.2	10.4	2.3	0	17	12.7	9.9	15.8	45.6	14.1	1.8	970
4	8.0	16.5	22.8	19.1	23.3	8.7	1.6	0	16	18.2	9.3	28.9	30.0	10.1	3.6	850
Mouth of Buffalo Creek, 22 July 1998, 0.62 m^3/s																
1	18.2	11.3	15.6	25.1	25.1	4.7	0	0	0.027	41.2	14.2	8.0	12.3	24.3	0	80
2	16.2	11.6	14.4	24.3	24.8	8.6	0	0	0.014	55.6	18.2	16.8	9.4	0	0	26
3	15.6	9.6	13.2	21.8	27.6	8.6	3.5	0	0.034	59.1	17.4	17.0	6.6	0	0	15
4	15.7	21.5	20.3	17.6	19.5	5.4	0	0	0.031	58.1	21.9	15.8	4.2	0	0	16
480 m upstream from the mouth of Buffalo Creek, 7 August 1998, 1.0 m^3/s																
1	12.8	15.1	23.3	22.8	18.8	6.9	0.2	0	5.8	26.7	14.9	28.5	25.8	3.8	0.4	1500
2	6.6	13.0	26.3	27.2	19.9	6.7	0.4	0	7.3	34.0	18.1	23.4	19.9	3.9	0.6	1500
3	13.4	20.4	26.1	17.8	15.7	5.9	0.7	0	6.7	21.7	17.8	27.5	27.9	4.4	0.7	1500
4	12.2	16.8	22.1	22.2	19.3	6.9	0.4	0	6.9	20.8	12.5	27.9	29.6	8.8	0.3	1900
Mouth of Buffalo Creek, 26 May 1999, 5.2 m^3/s																
1	7.1	13.1	23.1	30.0	20.2	5.8	0.6	0	28	28.8	15.9	22.7	20.4	9.2	3.1	1600
2	9.7	14.1	17.3	21.7	23.8	11.6	1.9	0	22	31.4	18.0	19.6	19.5	8.7	2.8	1600
3	7.7	13.6	19.8	25.3	22.8	9.3	1.6	0	23	34.6	7.1	33.6	19.5	3.7	1.5	1400
4	6.4	12.6	20.4	26.7	24.5	8.0	1.3	0	24	35.9	18.4	19.8	15.3	8.6	1.9	1400
Mouth of Buffalo Creek, 4 June 2000, 0.29 m^3/s																
1	8.4	10.4	17.0	28.8	28.8	6.7	0	0	0.0070	45.3	20.8	20.5	8.2	5.2	0	21
2	9.6	18.8	28.5	30.4	11.7	1.0	0	0	0.0051	41.0	23.0	19.6	13.8	2.6	0	14
3	6.6	12.8	20.8	26.6	26.3	7.0	0	0	0.0041	32.5	10.7	20.2	23.0	13.5	0	4.2

Table 6.5. Summary of sediment transport measurements in Spring Creek, 1997-2000

[τ, total bed shear stress; $u*$, mean shear velocity; $D*$ was used to separate bed load from suspended load and, therefore, the average sediment transport and concentration values may not agree with values in table 6.3 for the raw data; median diameter, D_{50}, was calculated by linear interpolation of the average cumulative distribution of the replicates; value given after ± is the 95% confidence limits; m, meter; m/s, meter per second; m^3/s, cubic meter per second; N/m^2, newton per square meter; kg/s, kilogram per second; kg/s/m, kilogram per second per meter; mg/L, milligram per liter; mm, millimeter]

							Sediment transport					Particle size		
Mean depth (m)	Width (m)	Slope	Mean velocity (m/s)	Discharge (m^3/s)	τ [a] (N/m^2)	$u*$ [a] (m/s)	Mean bed load (kg/s/m)	Mean bed load (kg/s)	Mean suspended load (mg/L)	Mean suspended load (kg/s)	Fraction < 0.063 mm (kg/s)	$D*$ [b] (mm)	D_{50} Bed load (mm)	D_{50} Suspended load (mm)
1997														
Wooden Parshall Flume at Mouth of Spring Creek, 28 June 1997														
0.064	0.61	0.04[c]	0.41	0.016[c]	25	0.16	0.12	0.076	1500	0.025	0.004	0.45	3.7	0.10
							±0.05	±0.032	±4300	±0.069	±0.006			
Wooden Parshall Flume at Mouth of Spring Creek, 2 July 1997														
0.034	0.61	0.04[c]	0.37	0.0078[c]	13	0.12	0.046	0.028	34	0.00027	0.00011	0.39[e]	4.8	0.074
							±0.020	±0.012	±35	±0.00027	±0.00027			
Wooden Parshall Flume at Mouth of Spring Creek, 11 July 1997[f]														
0.021	0.61	0.026	0.28	0.0036[d]	5.4	0.073	0.00030	0.00018	61	0.00022	0.00017	0.31	3.1	<0.063
							±0.00041	±0.00025	±86	±0.00031	±0.00026			
Grab sample collected at the gage on falling limb of flash flood, 29 July 1997														
0.33	8.7	0.041	1.7	5.0	130	0.36	no sample		9600	48	34		no analysis	
Wooden Parshall Flume at Mouth of Spring Creek, 3 August 1997														
0.067	0.61	0.030	0.54	0.022[d]	20	0.14	0.31	0.19	1700	0.037	0.017	0.42	4.8	0.078
							±0.20	±0.12	±280	±0.0062	±0.006			
Wooden Parshall Flume at Mouth of Spring Creek, 5 August 1997														
0.089	0.61	0.032	0.63	0.034[d]	28	0.17	0.95	0.58	5800	0.20	0.094	0.47	7.3	0.065
							±0.38	±0.23	±920	±0.031	±0.018			
Mouth of Spring Creek, 15 September 1997														
0.048	1.30[g]	0.032	0.61	0.038	15	0.12	0.11	0.14	400	0.016	0.0074	0.39	4.6	0.076
							±0.038	±0.05	±66	±0.0026	±0.0019			
Mouth of Spring Creek, 8 October 1997														
0.041	0.85	0.027	0.66	0.023	11	0.10	0.093	0.079	310	0.0071	0.0021	0.36	4.1	0.13
							±0.094	±0.080	±180	±0.0041	±0.00018			
1998														
Mouth of Spring Creek--Flume built from boulders, 21 May 1998														
0.050	2.7	0.030	1.2	0.16	15	0.12	0.96[h]	1.2	950	0.15	0.060	0.39	6.1	0.11
							±0.38	±0.46	±190	±0.030	±0.023			
Mouth of Spring Creek--Flume built from boulders, 26 June 1998														
0.047	2.0[i]	0.025	0.79	0.074	12	0.11	0.32[h]	0.40	430	0.032	0.013	0.38	5.4	0.10
							±0.10	±0.12	±90	±0.0067	±0.0040			
At gaging site on Spring Creek, 5 August 1998														
0.048	2.7	0.034	1.1	0.14	16	0.13	1.2	3.3	1900	0.27	0.095	0.41	5.5	0.12
							±0.59	±1.6	±960	±0.13	±0.031			

Table 6.5. (Continued) Summary of sediment transport measurements in Spring Creek, 1997-2000

							Sediment transport					Particle size		
Mean depth (m)	Width (m)	Slope	Mean velocity (m/s)	Discharge (m^3/s)	τ [a] (N/m^2)	u^* [a] (m/s)	Mean bed load (kg/s/m)	Mean bed load (kg/s)	Mean suspended load (mg/L)	Mean suspended load (kg/s)	Fraction < 0.063 mm (kg/s)	D^* [b] (mm)	D_{50} Bed load (mm)	D_{50} Suspended load (mm)
							1999							
							Mouth of Spring Creek, 15 May 1999							
0.065	1.4	0.027	1.1	0.10	17	0.13	0.71	1.0	620	0.062	0.020	0.41	5.1	0.13
							±0.45	±0.63	±150	±0.015	±0.010			
							Mouth of Spring Creek, 26 May 1999							
0.070	2.0	0.034	1.5	0.21	23	0.15	1.2	2.4	960	0.20	0.069	0.44	5.9	0.11
							±0.44	±0.88	±490	±0.10	±0.011			
							2000							
							Mouth of Spring Creek, 2 May 2000							
0.058	0.95	0.026	0.85	0.047	15	0.12	0.23	0.22	380	0.018	0.0035	0.39	3.5	0.26
							±0.18	±0.17	±60	±0.0028	±0.00066			

[a] Total bed shear stress was calculated as the product of the *water density x g x mean depth x slope* and the mean shear velocity was calculated as $u^* = \sqrt{g \cdot mean \cdot depth \cdot slope}$, where g=9.8 m/s^2.

[b] D^* is the particle diameter for a fall velocity equal to u^* assuming Stoke's or viscous settling ($D^* = \sqrt{\frac{18u^*\rho\nu}{(\rho_s - \rho) \cdot g}}$, where $\nu = 0.0116 \cdot cm^2/s$ for about 15°C, $g = 9.8 \cdot m/s^2$, and $(\rho_s - \rho)/\rho = 1.65$).

[c] An estimated slope was used.

[d] Discharges were determined from 2-ft Parshall Flume Table.

[e] Most of the 0.250-0.500 mm fraction of bed load should have been in the suspended load because D^*=0.39 mm. The amount of material in this size class was much greater than the smaller size class (0.125-0.250 mm) of the suspended load; therefore, the 0.250-0.500 mm fraction was grouped with the bed load.

[f] Algal growth stabilized the bed material.

[g] The mean depth for the discharge measurement was 0.046 m and the width was 1.40 m.

[h] Width of the moving bedload was 1.20 m.

[i] The width of the moving bed load was 1.25 m.

Table 6.6. Summary of sediment transport measurements in Buffalo Creek, 1997-2000

[τ , total bed shear stress; $u*$, mean shear velocity; $D*$ was used to separate bed load from suspended load and, therefore, the average sediment transport and concentration values may not agree with values in table 6.4 for the raw data; median diameter, D_{50} , was calculated by linear interpolation of the average cumulative distribution of the replicates; value given after ± is the 95% confidence limits; m, meter; m/s, meter per second; m^3/s, cubic meter per second; N/m^2, newton per square meter; kg/s, kilogram per second; kg/s/m, kilogram per second per meter; mg/L, milligram per liter; mm, millimeter]

							Sediment transport					Particle size		
Mean depth (m)	Width (m)	Slope	Mean velocity (m/s)	Discharge (m^3/s)	τ [a] (N/m^2)	$u*$ [a] (m/s)	Mean bed load (kg/s/m)	Mean bed load (kg/s)	Mean suspended load (mg/L)	Mean suspended load (kg/s)	Fraction < 0.063 mm (kg/s)	$D*$ [b] (mm)	D_{50} Bed load (mm)	D_{50} Suspended load (mm)
1997														
79 m upstream from the mouth of Buffalo Creek, 20 March 1997														
0.063	4.1	0.0093	0.68	0.18	5.7	0.076	0.044	0.18		no sample		0.31	1.6	--
							±0.054	±0.22						
79 m upstream from the mouth of Buffalo Creek, 1 July 1997														
0.074	8.4	0.0093	0.82	0.51	6.7	0.082	0.056	0.47	220	0.11	0.055	0.33	2.7	0.067
							±0.037	±0.31	±90	±0.046	±0.011			
79 m upstream from the mouth of Buffalo Creek, 14 July 1997														
0.053	9.3	0.010	0.55	0.27	5.2	0.072	0.055	0.51	120	0.032	0.016	0.30	2.3	0.067
							±0.012	±0.11	±41	±0.011	±0.0015			
480 m upstream from the mouth of Buffalo Creek, 14 July 1997														
0.064	5.6	0.011	0.69	0.25	6.9	0.083	0.11	0.55	130	0.032	0.014	0.33	2.9	0.076
	5.2[c]						±0.01	±0.05	±20	±0.0050	±0.0019			
72 m upstream from the mouth of Buffalo Creek, 19 August 1997														
0.070	7.3	0.011	0.86	0.44	7.5	0.087	0.21	1.3	870	0.38	0.16	0.33	2.9	0.089
	6.2[c]						±0.12	±0.77	±380	±0.17	±0.035			
about 90 m upstream from the mouth of Buffalo Creek, 1 September 1997														
0.096	5.0	0.013	0.98	0.47	12	0.11	0.36	1.8	2700	1.3	0.53	0.38	2.9	0.090
							±0.16	±0.82	±370	±0.17	±0.038			
about 90 m upstream from the mouth of Buffalo Creek, 3 November 1997; measurement made in the morning; 2 replicates														
0.094	6.3	0.015	1.03	0.62	14	0.12	0.40	2.5	970	0.60	0.12	0.39	3.2	0.20
							±0.60	±3.8	±850	±0.53	±0.24			
about 90 m upstream from the mouth of Buffalo Creek, 3 November 1997; measurement made in the afternoon; 4 replicates														
0.085	8.0	0.013	0.91	0.62	11	0.10	0.30	2.4	1000	0.62	0.14	0.36	3.1	0.19
							±0.12	±0.95	±130	±0.081	±0.038			
~79 m upstream from the mouth of Buffalo Creek; 7 November 1997														
0.11	7.5	0.015	1.0	0.87	16	0.13	0.41	3.1	900	0.78	0.19	0.41	3.2	0.17
							±0.076	±0.57	±210	±0.18	±0.025			

Table 6.6. (Continued) Summary of sediment transport measurements in Buffalo Creek, 1997-2000

							Sediment transport					Particle size		
Mean depth (m)	Width (m)	Slope	Mean velocity (m/s)	Discharge (m^3/s)	τ [a] (N/m^2)	$u*$ [a] (m/s)	Mean bed load (kg/s/m)	Mean bed load (kg/s)	Mean suspended load (mg/L)	Mean suspended load (kg/s)	Fraction < 0.063 mm (kg/s)	$D*$ [b] (mm)	D_{50} Bed load (mm)	D_{50} Suspended load (mm)
1998														
10 m upstream from the mouth of Buffalo Creek, 9 May 1998														
0.11	18.3	0.008	1.0[d]	2.1[d]	8.6	0.093	0.44 ±0.066	8.1 ±1.2	940 ±130	1.9 ±0.027	0.39 ±0.092	0.35	2.9	0.22
480 m upstream from the mouth of Buffalo Creek, 9 May 1998														
0.16	8.0	0.015	1.6	2.1	24	0.15	2.0 ±0.19	16.0 ±1.5	1000 ±140	2.1 ±0.29	0.29 ±0.048	0.44	3.0	0.26
190 m upstream from the mouth of Buffalo Creek, 22 July 1998														
0.14	6.9	0.015	0.63	0.62	21	0.14	0.0032 ±0.0017	0.022 ±0.012	32 ±17	0.020 ±0.011	0.010 ±0.011	0.42	3.1	0.06
480 m upstream from the mouth of Buffalo Creek, 7 August 1998														
0.096	8.3	0.014	1.3	1.0	13	0.11	0.71 ±0.16	5.9 ±1.3	1800 ±290	1.8 ±0.29	0.43 ±0.12	0.38	2.3	0.19
1999														
190 m upstream from the mouth of Buffalo Creek, 26 May 1999														
0.24	13.7	0.015	1.6	5.2	35	0.19	1.6 ±0.33	22 ±4.5	1400 ±140	7.3 ±0.73	2.5 ±0.23	0.50	3.0	0.12
2000														
210 m upstream from the mouth of Buffalo Creek, 4 June 2000														
0.15	4.0	0.0026	0.48	0.29	3.8	0.062	0.0014 ±0.00095	0.0054 ±0.0038	13 ±22	0.0038 ±0.0064	0.0016 ±0.0031	0.28	2.4	0.086

[a]Total shear stress was calculated as the product of the *water density x g x mean depth x slope* and the mean shear velocity was calculated as $u* = \sqrt{g \cdot mean \cdot depth \cdot slope}$, where g=9.8 m/s^2.

[b]$D*$ is the particle diameter for a fall velocity equal to $u*$ assuming Stoke's or viscous settling ($D* = \sqrt{\frac{18u*\rho\nu}{(\rho_s - \rho) \cdot g}}$, where $\nu = 0.0116 \cdot cm^2/s$ for about 15°C, $g = 9.8 \cdot m/s^2$, and $(\rho_s - \rho)/\rho = 1.65$).

[c]This is the width for the moving bed load.

[d]Discharge was estimated to be the same as 9 May 1998 at 480 m upstream fom mouth of Buffalo Creek.

Table 6.7. Threshold data for bed-load movement in Spring Creek

[Dimensionless shear stress, $\tau^* = \tau / (g \cdot (\rho_s - \rho) \cdot D_b)$; where τ is the total bed shear stress, g is 9.8 m/s^2, ρ_s is assumed to be 2,650 kg/m^3, ρ is density of water, and D_b is the median diameter of the largest class size moved; critical unit discharge for initiation of motion is greater than the mean discharge for calculating sediment transport in table 6.9; m, meter; m^3/s/m, cubic meter per second per meter; N/m^2, newton per square meter]

Date	Mean depth h (m)	Unit discharge (m^3/s/m)	Total bed shear stress τ (N/m^2)	Dimensionless shear stress τ^*	D_b (m)	Percent of total	$\frac{D_b}{h}$
			1997				
28 June	0.064	0.026	25	0.070	0.022	1.5	0.34
2 July	0.034	0.013	13	0.037	0.022	2.9	0.65
11 July[a]	0.021	0.0059	5.4	0.030	0.011	3.4	0.52
3 August	0.067	0.036	20	0.027	0.045	0.2	0.67
5 August[b]	0.089	0.056	28	0.019	0.091	2.3	1.0
15 Sept.	0.048	0.029	15	0.042	0.022	7.0	0.46
9 October	0.041	0.027	11	0.031	0.022	3.8	0.54
			1998				
21 May	0.050	0.059	15	0.021	0.045	3.2	0.90
26 June	0.047	0.037	12	0.034	0.022	2.7	0.47
9 July[c]	1.2	4.6	470	0.029	1.	<1.0	0.83
5 August	0.048	0.052	16	0.045	0.022	5.8	0.46
			1999				
15 May	0.065	0.071	17	0.048	0.022	4.9	0.34
26 May	0.070	0.10	23	0.032	0.045	0.4	0.64
			2000				
2 May	0.058	0.049	15	0.042	0.022	1.5	0.38

[a]Algae had grown on some of the particles on the bed.

[b]The sample had a high proportion of organic matter.

[c]The flash flood on 9 July 1998 moved a 1-m boulder located on section 1200.

Table 6.8. Threshold data for bed-load movement in Buffalo Creek

[Dimensionless shear stress, $\tau^* = \tau/(g \cdot (\rho_s - \rho) \cdot D_b)$; where τ is the total bed shear stress, g is 9.8 m/s^2, ρ_s is assumed to be 2,650 kg/m^3, ρ is density of water, and D_b is the median diameter of the largest class size moved; m, meter; m^3/s/m, cubic meter per second per meter; N/m^2, newton per square meter]

Date	Mean depth h (m)	Unit discharge (m^3/s/m)	Total bed shear stress τ (N/m^2)	Dimensionless shear stress τ^*	D_b (m)	Percent of total	$\frac{D_b}{h}$
			1997				
20 March	0.063	0.044	5.7	0.033	0.011	3.8	0.17
1 July	0.074	0.061	6.7	0.019	0.022	0.6	0.30
14 July[a]	0.053	0.029	5.2	0.015	0.022	0.4	0.42
14 July[a]	0.064	0.045	6.9	0.019	0.022	0.9	0.34
19 Aug.	0.070	0.060	7.5	0.010	0.045	0.5	0.64
1 Sept.[a]	0.096	0.094	12	0.034	0.022	0.9	0.23
3 Nov.[b]	0.094	0.098	14	0.039	0.022	1.9	0.23
3 Nov.[b]	0.085	0.078	11	0.031	0.022	1.2	0.26
7 Nov.	0.11	0.12	16	0.045	0.022	0.5	0.20
			1998				
9 May[c]	0.11	0.11	8.6	0.024	0.022	1.4	0.20
9 May[c]	0.16	0.26	24	0.033	0.045	0.3	0.28
22 July	0.14	0.090	21	0.059	0.022	0.9	0.16
7 Aug.	0.096	0.12	13	0.037	0.022	0.4	0.23
			1999				
26 May	0.24	0.38	35	0.098	0.022	1.4	0.092
			2000				
4 June	0.15	0.072	3.8	0.021	0.011	4.9	0.073

[a]First measurement was made about 79 m upstream from the mouth and the second measurement was made 480 m upstream from the mouth.

[b]Root obstructions were removed from channel and may have loosened the bed so the measurements were taken after waiting 30 minutes.

[c]Two replicates in the morning were combined with 4 replicates collected in the afternoon.

Table 6.9. Summary of total sediment transport estimates in Spring Creek for selected flash floods based on the change in volume of sediment in the study reach

[A bulk density of 1,700 kg/m^3 was used to convert from volume to mass; ΔV, change in volume of sediment in the study reach; Δt, estimated duration of flash flood D_s, maximum particle size in suspension; D_b, median diamater of largest size-class transported as bed load; q_s and q_b are the estimated suspended and bed load discharge; m, meter; s, second; m^3, cubic meter; m^3/s, cubic meter per second; m^3/s/m, cubic meter per second per meter; kg/s, kilogram per second; kg/s/m, kilogram per second per meter; mm, millimeter]

Date	Time-averaged depth[a] (m)	Width[a] (m)	Slope	Discharge[a] Peak (m^3/s)	Discharge[a] Time-averaged (m^3/s)	Discharge[a] Unit (m^3/s/m)	Total bed shear stress (N/m^2)	Mean shear velocity $u*$ (m/s)	ΔV (m^3)	Δt (s)	Total sediment discharge Q_T (kg/s)	Total sediment discharge q_T (kg/s/m)	Maximum particle size D_s[b] (mm)	Maximum particle size D_b[c] (mm)	Sediment discharge (kg/s/m) q_s[d]	Sediment discharge (kg/s/m) q_b[e]
1997																
29 July	0.23	7.3	0.04	5.0	2.5	0.34	90	0.30	630[f]	6,800	160	22	2.2	750	4.2	18
31 July	0.23	7.3	0.04	3.6	2.3	0.32	90	0.30	630[f]	6,000	180	25	2.2	750	4.8	20
26 Aug.	0.24	7.4	0.04	6.6	2.7	0.36	94	0.31	1,090[g]	6,300	290	39	2.3	790	7.5	31
31 Aug.	1.5	11.1	0.04	140	61	5.5	590	0.77	16,620[g]	7,200	3,900	350	11.0	>1,000	230	120
1998																
9 July	0.69	9.0	0.04	48	9.7	1.0	270	0.52	520	6,000	150	15	5.8	>1,000	7.5	7.5
31 July	1.1	10.4	0.04	82	37	3.7	430	0.66	1,300	1,800	1,200	120	7.9	>1,000	71	49
1999																
29 July	0.30	5.9	0.04	6.4	1.7	0.29	120	0.34	410[h]	9,000	80	14	2.6	>1,000	2.8	11

[a]Used Nash's (1958) linear reservoir model with n=3, and K ranging from 3.5-10.5 minutes, and the peak discharge to estimate the hydrograph by conserving the volume, which was measured at the gage site or downstream at the South Platte gage site if the Spring Creek gage malfunctioned. Time-averaged discharge was the volume of water divided by the duration of the flash flood. Time-averaged depth was determined from the discharge and the critical flow model applied to the geometry of the gage site (see table 3.5).

[b]D_s was determined by iterating until Dietrich's (1982) fourth-order polynomial equation, which predicts settling velocity, equalled $u*$.

[c]Solved the empirical equation for initiation of motion $\tau* = 0.021 \cdot \left(\frac{D_b}{h}\right)^{-0.88}$ for D_b, where h is the time-averaged depth and $\tau*$ is given by equation 6.5.

[d]Suspended load was proportional to the percent finer than D_s based on Appendix 12.

[e]Bed load was proportional to (the percent finer than D_b minus the percent finer than D_s) based on Appendix 12.

[f]The two flash floods had the same magnitude so the total change in volume (1,260 m^3) between 25 July and 6 August 1997 was proportioned equally.

[g]The total change in volume between channel surveys on 6 August and 31 August 1997 (17,720 m^3, Table 5.2) was distributed to each flash flood by assuming the volume was proportional to the unit discharge.

[h]The flash flood eroded 410 m^3 between the mouth and 679 m upstream from the mouth; it deposited 330 m^3 between 679 m and 1,470 m.

Table 6.10. Bed-load transport efficiencies for selected streams and rivers

[Efficiency, 100 x bed-load transport rate/water discharge; bed characteristics are the averages where data were available; D_{50}, median diameter of bed material; m^3/s, cubic meter per second; mm, millimeter; %, percent]

Location	Range of discharge (m^3/s)	Typical Slope	Typical D_{50} (mm)	Efficiency Minimum Maximum (%)	Reference
Rio Solimoès and Rio Amazon between Iquitos, Peru and Obidos, Brazil	43,600 235,000	0.00005	0.2	0.00081 0.0035	Posada, 1995.
Tanana River at Fairbanks, Alaska	345 2,020	0.0005	5	0.00070 0.0068	Burrows and others, 1981. Williams and Rosgen, 1989.
Toutle River at Tower Road near Silver Lake, Washington	12.0 592	0.003	no data	0.0077 0.17	Williams and Rosgen, 1989.
East Fork River near Pinedale, Wyoming	2.67 22.4	0.0007	3	0.0023 0.033	Williams and Rosgen, 1989.
Muddy Creek near Pinedale, Wyoming	0.18 1.57	0.0012	no data	0.0014 0.058	Williams and Rosgen, 1989.
Nahal Yael, southern Negev, Israel	0.032 0.36	0.08	4	0.018 7.5	Lekach and others, 1992. Lekach and Schick, 1983.
Oak Creek, Oregon	0.15 3.4	0.01	3	0.000000075 0.018	Milhous, 1973.
Buffalo Creek at Buffalo Creek, Colorado (pre-fire)	0.42 1.56	0.02	no data	0.0011 0.087	Williams and Rosgen, 1989.
Buffalo Creek at mouth near Buffalo Creek, Colorado (postfire)	0.25 5.2	0.02	2	0.0019 0.76	This report.
Spring Creek at mouth near South Platte, Colorado (post-fire)	0.0078 0.21	0.04	5	0.34 2.3	This report.

Table 6.11. Ratio of the percent sediment transported as bed load to the percent sediment available in the bed of Spring Creek

[Percent sediment available depends upon the size classes transported only as bed load (see table 6.4 which gives raw values) and the bed-material size distribution given in table 6.1 which was recalculated by including only the bed-load size classes; D_b , median diamater of largest size-class transported as bed load; h, water depth; mm, millimeter; N/m^2, newton per square meter; m^3/s/m, cubic meter per second per meter; nm, not moving]

Date	Ratio = Sediment Transported / Sediment Available										D_b/h	Total shear stress (N/m^2)	Unit discharge (m^3/s/m)
	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	64-128 mm			
1997													
28 June	in suspension		1.76	1.65	1.13	0.76	0.86	0.37	nm	nm	0.34	25	0.026
2 July	in suspension		0.88	1.18	1.02	0.88	1.25	0.70	nm	nm	0.65	13	0.013
11 July[a]	in suspension		1.63	1.94	1.43	0.71	0.21	nm	nm	nm	0.52	5.4	0.0059
3 August	in suspension		1.36	1.08	1.07	1.00	1.38	0.80	0.03	nm	0.67	20	0.036
5 August	in suspension		1.11	0.69	0.75	0.92	2.22	3.86	0.25	0.19	1.0	28	0.056
15 Sept.	in suspension		1.02	1.21	1.06	0.71	1.29	1.72	nm	nm	0.46	15	0.029
9 Oct.	in suspension		1.73	1.49	1.01	0.69	1.21	0.94	nm	nm	0.54	11	0.027
1998													
21 May	in suspension		1.29	0.85	0.79	0.97	1.69	1.42	0.38	nm	0.90	15	0.059
26 June	in suspension		0.68	0.97	0.92	0.96	1.46	0.65	nm	nm	0.47	12	0.037
5 August	in suspension		1.08	0.96	0.83	0.88	1.48	1.40	nm	nm	0.46	16	0.052
1999													
15 May	in suspension		0.88	1.03	0.93	0.88	1.36	1.19	nm	nm	0.34	17	0.071
26 May	in suspension		0.95	0.87	0.89	0.92	1.81	1.91	0.05	nm	0.64	23	0.10
2000													
2 May	in suspension		2.34	1.46	0.86	0.84	1.06	0.37	nm	nm	0.38	15	0.049

[a]Algae was growing on the bed material.

Table 6.12. Ratio of the percent sediment transported as bed load to the percent sediment available in the bed of Buffalo Creek

[Percent sediment available depends upon the size classes transported only as bed load (see table 6.4 which gives raw values) and the bed-material size distribution given in table 6.1 which was recalculated by including only the bed-load size classes; D_b , median diamater of largest size-class transported as bed load; h, water depth; mm, millimeter; N/m^2, newton per square meter; m^3/s/m, cubic meter per second per meter; nm, not moving]

Date	Ratio = Sediment Transported / Sediment Available										D_b/h	Total shear stress (N/m^2)	Unit discharge (m^3/s/m)
	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm	32-64 mm	64-128 mm			
1997													
20 March	in suspension		1.70	1.33	0.91	0.67	0.44	nm	nm	nm	0.17	5.7	0.044
1 July	in suspension		1.08	1.05	0.97	1.00	1.01	0.38	nm	nm	0.30	6.7	0.061
14 July	in suspension		1.22	1.16	1.02	0.90	0.75	0.24	nm	nm	0.42	5.2	0.029
14 July	in suspension		0.93	1.01	1.07	1.05	0.86	0.48	nm	nm	0.34	6.9	0.045
19 August	in suspension		0.85	0.98	1.06	1.02	1.11	1.18	0.38	nm	0.64	7.5	0.060
1 Sept.	in suspension		1.18	1.05	0.99	0.96	0.89	0.54	nm	nm	0.23	12	0.094
3 Nov.[a]	in suspension		0.97	0.96	1.02	0.98	1.17	0.81	nm	nm	0.24	12	0.080
1998													
9 May	in suspension		1.25	1.03	0.89	0.98	1.00	0.85	nm	nm	0.20	8.6	0.11
9 May	in suspension		1.07	1.08	0.95	1.02	1.01	0.79	0.21	nm	0.28	24	0.26
22 July	in suspension		1.19	0.89	0.98	1.11	0.84	0.54	nm	nm	0.16	21	0.090
7 August	in suspension		1.35	1.29	0.94	0.80	0.76	0.25	nm	nm	0.23	13	0.096
1999													
26 May	in suspension		1.07	1.02	1.04	0.95	0.97	0.76	nm	nm	0.092	35	0.24
2000													
4 June	in suspension		1.10	1.10	1.13	0.91	0.54	nm	nm	nm	0.073	3.8	0.072

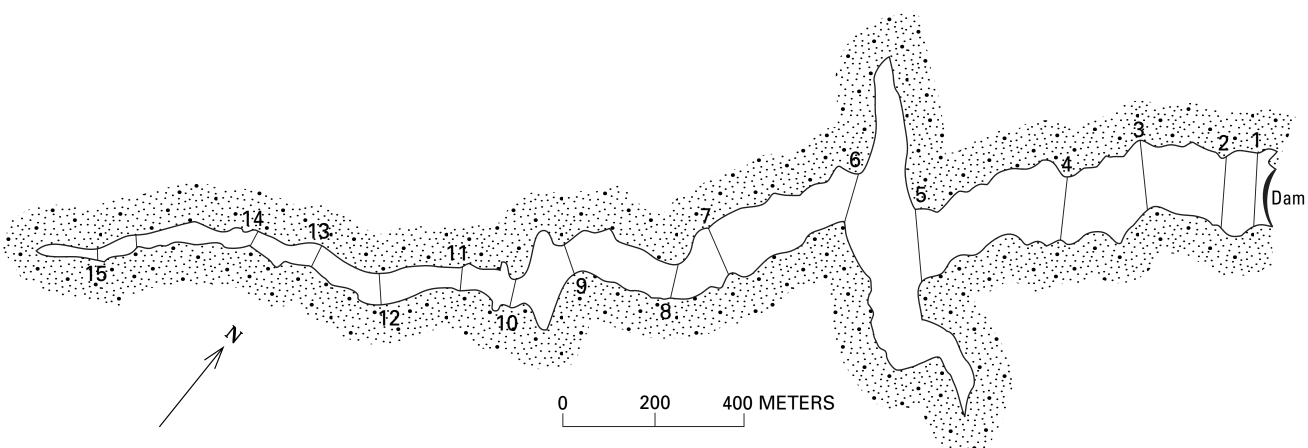
[a]The morning and afternoon measurements were averaged.

Section 7--RESERVOIR

Methods

Strontia Springs Reservoir is approximately 2,700 m long and 150 m wide (fig. 7.1) and traps coarse sediments (sand and gravel) in the upstream end and fine sediments (silt and clays) in the downstream end. Coarse sediment deposition in the reservoir was monitored after the Buffalo Creek Fire by measuring a single bathymetric profile along the center line using an acoustical fathometer (Lowrance Model X16). This was sufficient to represent the average bottom elevation and also avoided problems of sound scattering in the vicinity of steep canyon walls. Distances were measured downstream from the Denver Water Department station 15 (fig. 7.1), near the upper end of the reservoir. The Denver Water Department monumented stations with brass bench marks on both sides of the reservoir and above the normal pool elevation (1,829 m or 6,002 feet). Distances between stations were divided into ten equal intervals and the longitudinal profiles were digitized at these intervals, which were not necessarily equal along the entire profile (Appendix 13). The distances and elevations (corrected for actual water-level elevation) for each survey are in files on the accompanying CD and the format of these files is listed in Appendix 14.

To calculate the change in volume of coarse sediment, it was assumed that the sediment formed a horizontal surface across the reservoir. The change in volume of coarse sediment (sand and gravel) that accumulated in the upper end of Strontia Springs Reservoir between bathymetric surveys was calculated from the difference in elevation between the longitudinal bathymetric profiles and using the widths of the canyon, measured from a topographic map (scale 1 inch = 200 feet) provided by the Denver Water Department. Average sediment transport rates into the reservoir were estimated by dividing the change in volume by the time between bathymetric surveys. Conversion between sediment volume and sediment mass was calculated using an average bulk density of 1,700 kg/m^3 based on bed-load material collected in Buffalo and Spring Creeks. These data and calculated results are shown in table 7.1.



STRONTIA SPRINGS RESERVOIR CHARACTERISTICS

Normal pool elevation	1,829 m
Capacity at elevation 1,829	9,500,000 m^3
Surface area at elevation 1,829	460,000 m^2
Length	2,700 m
Average depth	24 m
Average width	148 m

Figure 7.1 Strontia Springs Reservoir on the South Platte River near Denver. The numbers along the edge of the reservoir indicate sections that have benchmarks maintained by the Denver Water Department.

Samples of the fine-sediment fraction (silt and clays) were obtained in February and March 1997 by using a gravity corer through the ice at stations 4 and 7 (fig. 7.1). A modified Wildco corer (approximately 5-cm diameter) with 6.4 kg of lead clamped onto the stainless-steel barrel was allowed to free fall from about 3 m above the bottom and then was driven into the sediment using a 18-kg weight. This technique produced a 1.39-m-long core (core 4B) at station 4 and a 0.74-m-long core (core 7A) at station 7.

Subsamples were analyzed from core 4B at 0.02-0.04 m, 0.50-0.52 m, 0.90-0.92 m, and 1.06-1.08 m below the sediment surface for particle size, loss on ignition, and metals analysis. The sediment was analyzed by sequential extraction digestion (Hayes, 1993) which gave results for 47 elements and silicon dioxide. Bulk density and particle size were also determined for subsamples collected from 0-0.20 m, 0.20-0.50 m, 0.52-0.80 m, 0.80-0.99 m, and 0.99-1.39 m. A sample was also analyzed from core 7A for particle size at 0.49-0.74 m below the sediment surface.

Results

Sediment Deposition and Transport into the Reservoir

Strontia Springs Reservoir trapped most of the coarse- and fine-grained sediment from the burned watersheds. The reservoir is relatively small, with an 85 percent trapping efficiency (Borland, 1978) that retains the coarsest fraction (sands and gravels) but passes some of the fine fraction, depending upon the size of the flood and how much water is being released at the dam. The initial floods in 1996 were so large that they transported some of the bed-load and suspended-load sediment from the burned watersheds into the reservoir in a few hours or days (table 7.1). Part of the suspended load (silt and clay) was trapped in the reservoir near the dam, but some passed through the reservoir during the 1996 flash flood and was trapped behind the Marston Diversion and Chatfield Dams farther downstream. The bed load, however, settled out and created a delta with an approximately 10-m high slip face (fig. 7.2A, Sept. 1996) in the upper end of Strontia Springs Reservoir. Measurements of the delta indicated that 52,000 m^3 of fire-related, coarse-grained sediment was deposited on top of existing sediment (fig. 7.2, 7.3 and table 7.1). On the basis of a few sediment cores collected from the lower end of the reservoir during the winter of 1996-97, we estimated 0.5 m of fine grained sediment (about 100,000 m^3) was deposited in the reservoir. Field measurements indicated an additional 2,500 m^3 of mostly fine grained sediment (12 percent clay, 66 percent silt, 21 percent sand, and 1 percent gravel) was deposited downstream from the Marston Diversion Dam. Thus, the total sediment deposition in 1996 was about 154,000 m^3.

Reservoir operations in September-October 1996 lowered the water level about 20 m. As a result, the water cut a channel down through the upstream delta exposing a black layer of fire-related sediment (black band in fig. 7.2A, fig. 7.3), as well as sediment deposited before the wildfire. This initial channel later expanded laterally, eventually eroded most of the original sediment in the delta, transported it farther downstream into the reservoir (table 7.1, September 13 to October 2, 1996), and deposited it between Stations 12 and 9 (fig. 7.2A, June 1997). A new delta formed about 300 m downstream from station 15 by June 1997. This face advanced about 200 m down the reservoir between June and September 1997, probably as a result of the severe flash floods during the summer of 1997. It advanced farther into the reservoir (about 120 m) during the spring of 1998 (fig. 7.2B, May 1998) when reservoir operations again lowered the water level of

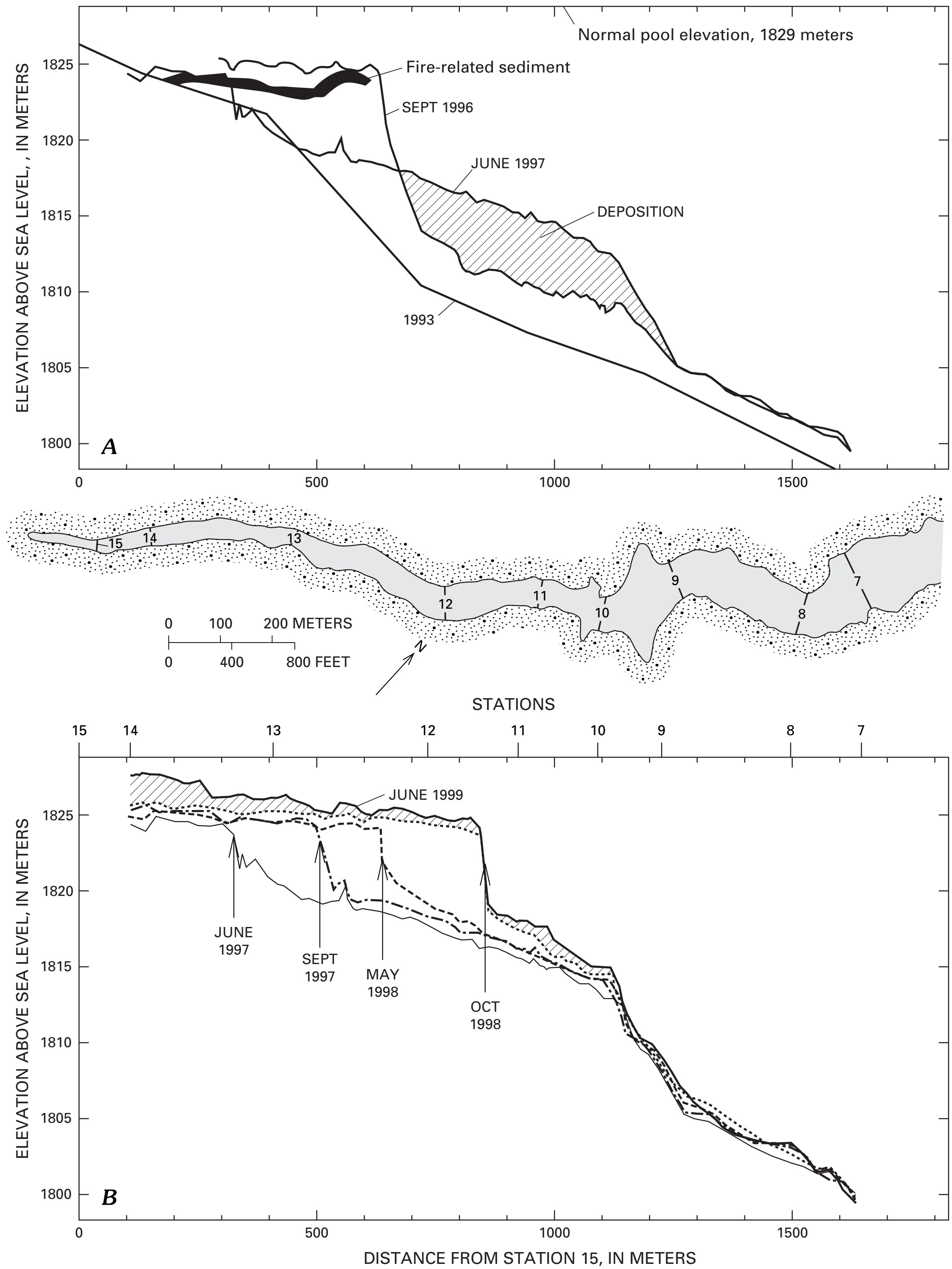


Figure 7.2 A. Longitudinal profiles of the upper part of Strontia Springs Reservoir. The original bottom is shown by the 1993 profile. The black layer in the Sept. 1996 profile represents the initial deposit of fire-related sediments that was later covered by fire-related coarse sand and gravel. The area of subsequent deposition (shown by cross hatching) was caused by erosion of the delta shown in Sept. 1996 when the water level in the reservoir was lowered. B. Successive longitudinal profiles are shown and the June 1997 profile is repeated from Figure 7.2A

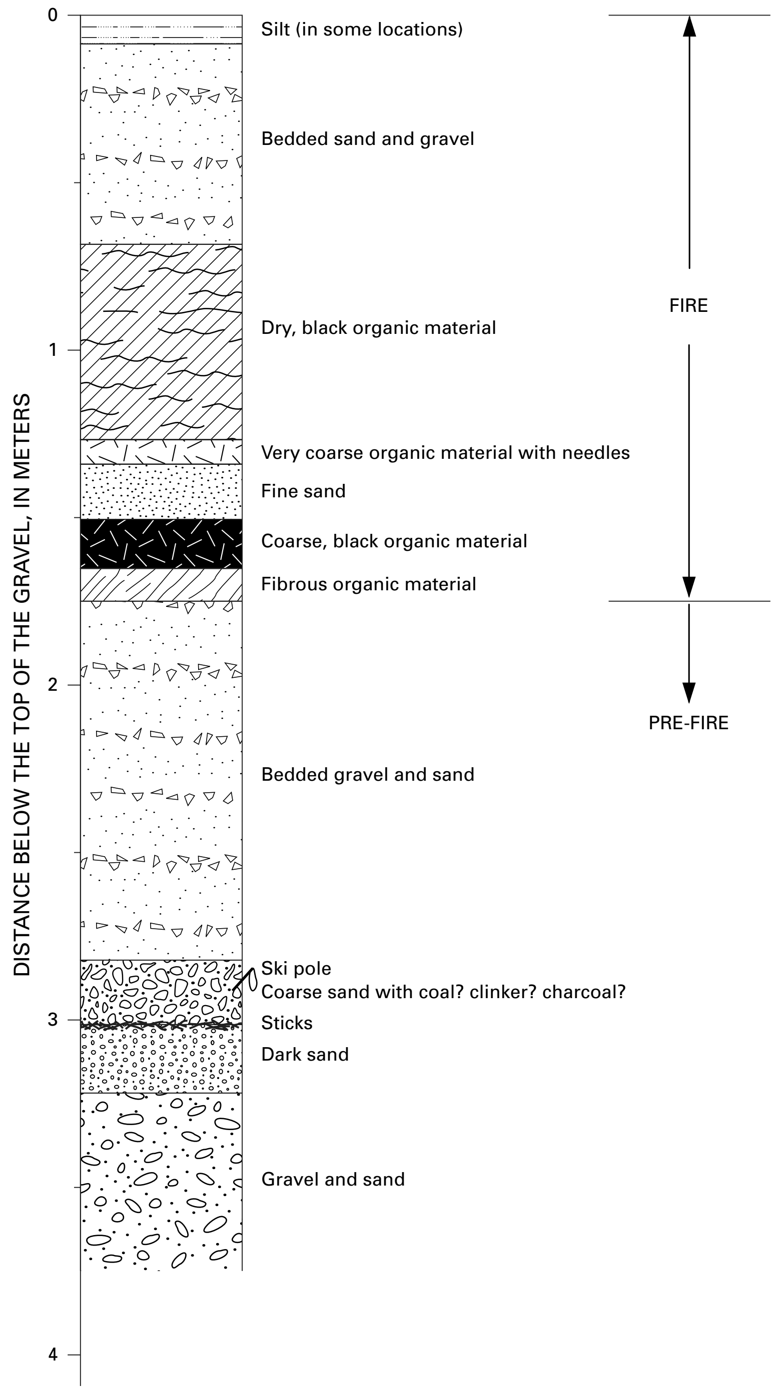


Figure 7.3 Stratigraphy of flood sediments at section 12-13 in Strontia Springs Reservoir.

the reservoir and the sediment transport rates increased (table 7.1, 22 May to 15 June 1998).

Flash floods later in July 1998 probably moved this face downstream an additional 210 m by October 1998 to a new location between Stations 11 and 12, where it remained through 4 June 1999. Additional sediment has been added to the delta since October 1998, not by advancing the face downstream, but by increasing the height of the delta in the upper end of the reservoir. This is perhaps in response to maintaining a higher level of the reservoir (above 1,829 m) during the spring of 1999.

Sediment transport rates into the reservoir after 1996 reflect the complex response of reservoir operations and the transport and storage of sediment upstream. The pre-fire, bed-load transport rate of the South Platte River (0.86 kg/s) was measured by Borland (1978) before the Strontia Springs Dam was built. Bed-load transport rates into the reservoir after the wildfire ranged from 0.89 kg/s to 310 kg/s (table 7.1). This range of transport rates probably depended upon (1) sediment storage in the channel reach upstream from the reservoir, (2) operation of Strontia Springs Reservoir, and 3) operation of other reservoirs upstream of the storage reach. For example, the transport rate after the flash flood on 31 August 1997 seems relatively low (2.0 kg/s). Sediment from this flood was probably stored in the channel reach upstream from Strontia Springs Reservoir because discharge from the other upstream reservoirs was decreased near the end of the summer. The sediment was then transported (18 kg/s) during the following spring when Strontia Springs Reservoir was lowered and water was released from other upstream reservoirs.

Sediment Cores

The interface between wildfire-related sediments and pre-fire sediments was distinct in only one core (4B). This interface was 0.99 m below the sediment surface, and the material above this interface fined upward from 65 percent silt and clay to 99.5 percent silt and clay (table 7.2 and fig. 7.4). Silty material just above the interface had a bulk density of 1,520 kg/m^3 with an organic content of 11 percent while the fibrous organic material below the interface had a bulk density of 1,200 kg/m^3 and an organic content of 41 percent. Measured concentrations of six metals (table 7.3) increased above the interface between pre-fire and fire-related sediment (fig. 7.5). This is associated with a decrease in particle size (table 7.2 and fig. 7.4), which is known to affect metal concentrations (Horowitz, 1991).

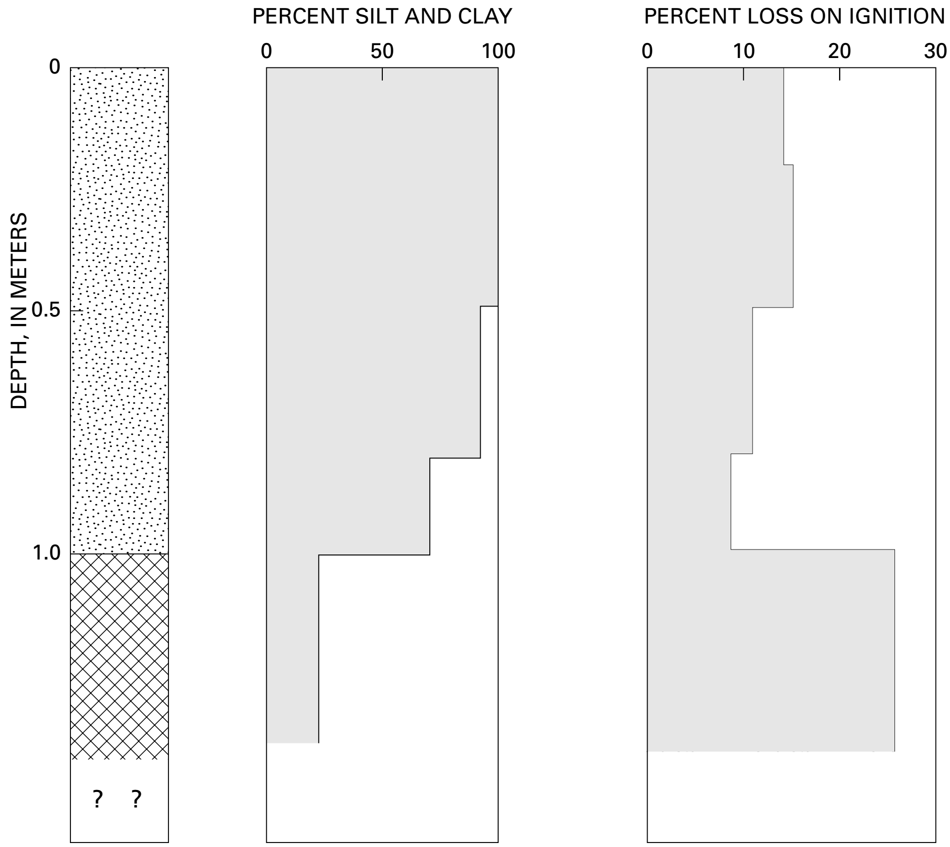


Figure 7.4 Changes in percent silt and clay and material lost on ignition (LOI) in a sediment core. Sediment core 4B was collected near section 4 in the middle of Strontia Springs Reservoir (see fig. 7.1). The stippling represents fire-related sediment above the interface at 99 cm. The cross-hatching represents pre-fire sediment collected after the reservoir was filled with water.

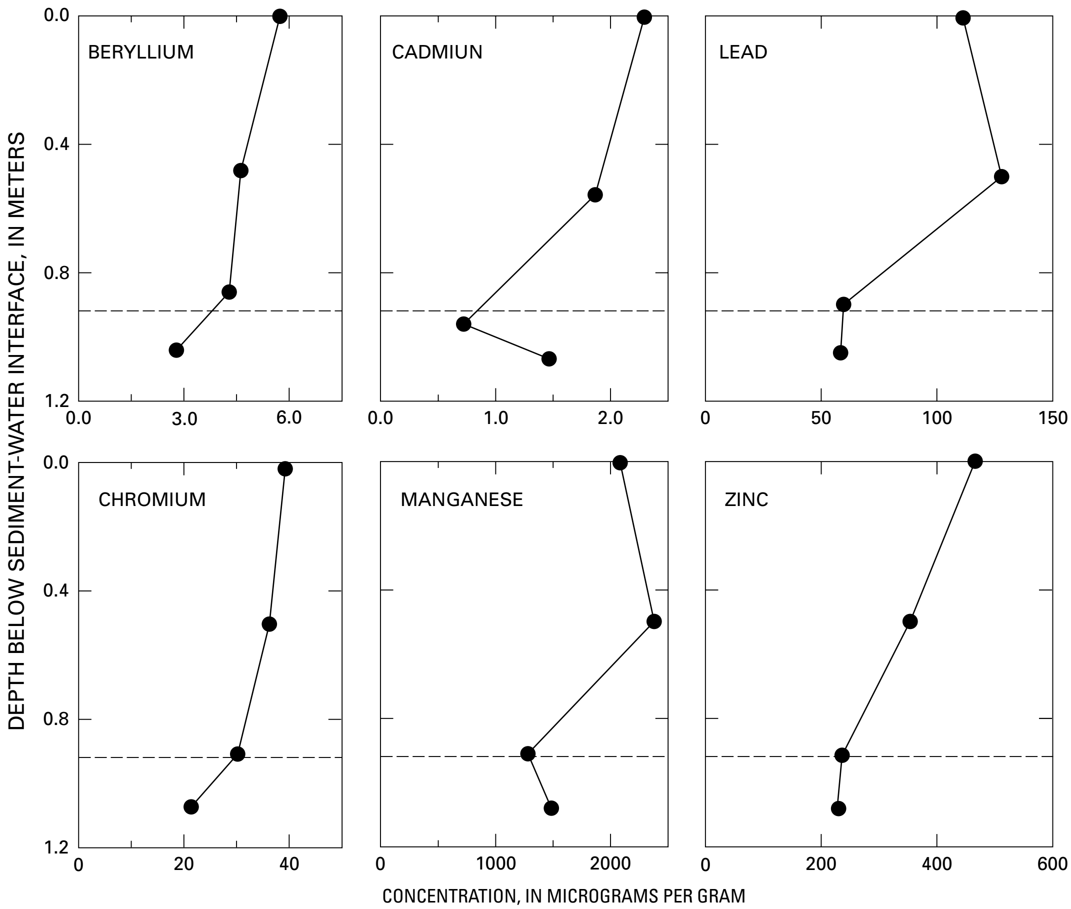


Figure 7.5 Change in metal concentrations in a sediment core. Sediment core 4B was collected near section 4 in the middle of Strontia Springs Reservoir (see fig. 7.1). The dashed line represents the interface between pre-fire sediments below and fire-related sediments above.

Table 7.1. Measurements of coarse (sand and gravel) sediment deposition and transport into Strontia Springs Reservoir based on changes in sediment volume in the reservoir

[Used a bulk density of 1,700 kilograms per cubic meter; m^3, cubic meter; m^3/d, cubic meter per day; kg/s, kilogram per second; kg/s/m, kilogram per second per meter]

Deposition period	Days	Sediment volume (m^3)	Sediment transport rate			Comments
			Volume (m^3/d)	Mass (kg/s)	per unit width[a] (kg/m/s)	
			1996			
May 18, 1996 - September 13, 1996	2	31,000	16,000	310	16	Initial input was estimated to occur in 2 days.
September 13, 1996 - October 2, 1996	19	21,000	1,100	22	1.1	Reservoir level was lowered during deposition period.
			1997			
October 2, 1996 - June 27, 1997	268	12,000	45	0.89	0.044	Winter.
June 27, 1997 - August 13, 1997	47	21,000	450	8.9	0.44	--
August 13, 1997 - September 12, 1997	30	3,100	100	2.0	0.10	Large flash flood occurred on August 31.
			1998			
September 12, 1997 - May 22, 1998	252	41,000	160	3.1	0.16	Winter.
May 22, 1998 - July 15, 1998	54	50,000	930	18	0.90	Water level was lowered during the spring.
July 15, 1998 - August 3, 1998	19	30,000	1,600	31	1.6	Large flash flood occurred on July 31.
August 3, 1998 - October 23, 1998	81	15,000	190	3.7	0.18	--
			1999			
October 23, 1998 - June 4, 1999	224	26,000	120	2.4	0.12	Winter.

Table. 7.2. Summary of particle-size distribution of fire-related sediments collected from Strontia Springs Reservoir and upstream from the Marston Diversion Dam

[m;, meter; mm, millimeter; *, mostly organic material]

Depth from top (m)	Percent of total sample										
	< 0.004 mm	0.004-0.063 mm	0.063-0.125 mm	0.125-0.250 mm	0.250-0.500 mm	0.500-1.00 mm	1-2 mm	2-4 mm	4-8 mm	8-16 mm	16-32 mm
Vertical profile of deltaic sediments ~40 m upstream from Station 12-13 on left bank--1997											
surface	3.6	39.3	31.0	14.3	*4.7	*7.1	0.0				
0.01-0.60	0.0	0.0	0.4	3.7	14.5	15.7	12.3	14.7	19.3	15.5	3.7
0.60-1.20	1.6	25.0	42.0	23.4	5.1	2.8	0.0				
1.20-1.28	3.6	28.7	26.2	16.2	7.3	*18.0	0.0				
1.28-1.45	2.7	19.9	53.1	18.4	*0.6	*5.3	0.0				
1.45-1.60	18.7	38.6	17.2	11.0	7.4	7.1	0.0				
1.60-1.70	11.4	27.3	27.9	11.9	5.0	*16.5	0.0				
1.70-2.80	<0.1		0.1	0.5	2.5	10.1	20.0	27.4	22.3	17.1	0.0
2.80-3.00	3.5		1.1	2.8	27.0	28.2	7.9	6.8	4.1	18.6	0.0
3.00-3.20	2.1	11.8	9.7	*68.1	*7.7	*0.6	0.0				
Sediment core collected near Station 4--1997											
0.00-0.20	38.4	61.1	0.4	0.1	0.0						
0.20-0.50	39.8	58.6	1.4	0.1	0.0						
0.50-0.80	12.2	79.9	6.7	1.0	0.2	*0.1	0.0				
0.80-0.99	9.6	55.4	24.0	*8.7	*1.6	*0.7	0.0				
0.99-1.395	2.8	17.8	38.0	*18.4	*6.1	*16.9	0.0				
Sediment core collected near Station 7--1997											
0.49-0.74	13.8	76.3	9.4	0.4	*0.1						
Sediment collected ~300 m upstream from the Marston Diversion Dam--1996											
high water	22.8	67.3	2.4	0.9	1.0	0.7	0.5	1.2	3.2	0.0	
2 m below high water	14.9	67.8	12.9	3.4	0.9	0.0					
4 m below high water	3.9	57.1	24.9	13.8	0.2	0.0					
Sediment collected ~500 m upstream from the Marston Diversion Dam--1996											
high water	7.0	71.9	16.3	3.4	1.3	0.1	0.0				

Table 7.3. Metals associated with hillslope source material and fire-related bed sediments in Strontia Springs Reservoir

[See fig. 7.3 for profile of fire-related sediments in the delta in Strontia Springs Reservoir; see fig. 7.4 for profile of Core 4B; m, meter; g, gram; all concentrations are in micrograms per gram; na, not available. Buffalo River Standard is National Institute of Standards and Technology standard reference material 2704.]

	Buffalo River Standard		Hillslope Source Material				Delta		Strontia Springs Core 4B			
			Buffalo Creek			Spring Creek						
	Observed	Certified	Un-burned soil	Burned soil	Burned eroded silt	Ash	0.6-1.2 m below surface	1.5-1.6 m below surface	0.02-0.04 m below surface	0.50-0.52 m below surface	0.09-0.92m below surface	1.06-1.08 m below surface
Mass (g)			0.0931	0.0946	0.1047	0.0941	0.0985	0.0952	0.0965	0.0976	0.0971	0.0962
Al	56300 ±4800	61100 ±1600	40000 ±1000	49000 ±1000	37000 ±0	30000 ±0	45000 ±0	38000 ±0	49000 ±1000	34000 ±1000	37000 ±1000	36000 ±1000
As	<50 ±na	23.4 ±1	<50±1	<50±1	<50±0	<5±10	<50±1	<50±1	<50±1	<50±0	<50±1	<50±0
Ba	387 ±32	414 ±12	600 ±10	510 ±10	480 ±0	870 ±20	540 ±0	670 ±0	590 ±10	420 ±10	450 ±10	560 ±10
Be	1.9 ±0.3	na	3.6 ±0.0	4.3 ±0.3	4.2 ±0.1	1.7 ±0.1	5.0 ±0.1	3.4 ±0.2	5.5 ±0.1	4.7 ±0.1	4.3 ±0.1	2.8 ±0.1
Bi	0.8 ±0.3	na	0.5 ±0.0	<0.5 ±0.0	0.8 ±0.0	0.8 ±0.0	0.9 ±0.0	1.7 ±0.1	1.1 ±0.0	1.1 ±0.0	0.7 ±0.0	0.9 ±0.0
Ca	26700 ±700	26000 ±300	5000 ±100	5700 ±100	15000 ±0	[a]170000 ±0	13000 ±0	18000 ±0	9600 ±200	13000 ±0	13000 ±0	18000 ±0
Cd	3.41 ±0.32	3.45 ±0.22	1.1 ±0.0	<0.6 ±0.1	1.6 ±0.0	6.0 ±0.0	0.8 ±0.0	2.4 ±0.0	2.3 ±0.1	1.9 ±0.2	0.8 ±0.0	1.5 ±0.0
Ce	54 ± 8	72	76 ±5	230 ±10	290 ±0	69 ±3	190 ±0	200 ±0	350 ±10	350 ±0	200 ±0	220 ±0
Co	13.7 ±0.7	14.0 ±0.6	9 ±0	8 ±0	10 ±0	23 ±1	11 ±0	10 ±0	14 ±0	13 ±0	10 ±0	8 ±0
Cr	134 ±8	135 ±5	37 ±3	27 ±3	26 ±0	24 ±1	23 ±2	26 ±1	39 ±0	36 ±3	30 ±3	21 ±3
Cs	6.0 ±0.6	6	5.6 ±0.4	6.7 ±0.2	4.0 ±0.4	3.3 ±0.4	4.7 ±0.2	4.1 ±0.3	6.9 ±0.2	4.6 ±0.0	5.1 ±0.0	3.6 ±0.4
Cu	98.6 ±11.3	98.6 ±5	[a]1400 ±0	98 ±0	24 ±1	44 ±1	22 ±0	26 ±1	41 ±1	32 ±1	18 ±1	20 ±1
Dy	4.5 ±0.3	6	5 ±0	17 ±1	11 ±0	4 ±0	15 ±0	10 ±0	20 ±0	20 ±0	15 ±1	12 ±0
Er	2.7 ±0.2	na	4 ±0	14 ±1	7 ±0	3 ±0	10 ±0	6 ±0	12 ±0	12 ±0	9 ±0	7 ±0
Eu	1.1 ±0.1	1.3	0.7 ±0.0	1.5 ±0.1	1.2 ±0.0	0.6 ±0.0	1.3 ±0.0	1.3 ±0.0	1.7 ±0.0	2.3 ±0.0	1.5 ±0.0	1.1 ±0.0
Fe	41700 ±1300	41100 ±1000	37000 ±0	51000 ±1000	46000 ±0	16000 ±0	58000 ±0	41000 ±0	66000 ±1000	62000 ±1000	51000 ±1000	35000 ±0
Gd	6.9 ±0.6	na	6 ±0	20 ±1	15 ±1	7 ±0	20 ±1	15 ±1	29 ±1	31 ±0	21 ±1	19 ±0
Ho	0.8 ±0.1	na	1.0 ±0.0	3.5 ±0.1	2.0 ±0.1	0.8 ±0.0	2.7 ±0.1	1.8 ±0.0	3.6 ±0.0	3.6 ±0.1	2.8 ±0.0	2.1 ±0.1
La	22 ±5	29	28 ±1	96 ±1	99 ±0	32 ±1	67 ±1	77 ±2	150 ±0	140 ±10	79 ±0	87 ±1
Li	44.3 ±1.8	48 ±4.1	44 ±1	79 ±2	53 ±1	15 ±1	54 ±1	44 ±0	65 ±0	64 ±2	44 ±1	28 ±1
Lu	0.4 ±0.0	0.6	0.9 ±0.0	2.6 ±0.0	1.2 ±0.0	0.4 ±0.0	1.6 ±0.0	1.0 ±0.0	1.7 ±0.1	1.8 ±0.1	1.5 ±0.0	1.0 ±0.0
Mg	10800 ±1100	12000 ±200	3000 ±100	6500 ±100	3200 ±0	8500 ±200	5200 ±0	4800 ±0	6700 ±100	3200 ±100	3500 ±0	5300 ±0
Mn	572 ±16	555 ±19	1700 ±0	1100 ±0	1900 ±0	1400 ±0	1600 ±0	2300 ±0	2100 ±0	2400 ±0	1300 ±0	1500 ±0
Mo	3 ±0	na	<3 ±0	<3 ±0	<3 ±0	3 ±0	<3 ±0	<3 ±0	<3 ±0	<3 ±0	<3 ±0	<3 ±0
Na	6970 ±1910	5470 ±140	14000 ±0	13000 ±0	12000 ±0	4400 ±300	18000 ±0	11000 ±0	11000 ±1000	10000 ±1000	16000 ±1000	10000 ±0
Nd	25 ±3	na	28 ±1	86 ±1	83 ±1	28 ±1	80 ±1	72 ±1	140 ±0	150 ±10	90 ±2	87 ±2
Ni	46.6 ±7.1	44.1 ±3	19 ±1	16 ±2	15 ±0	20 ±0	17 ±0	15 ±1	27 ±1	24 ±1	19 ±0	16 ±1
Pb	157 ±8	161 ±17	97 ±3	59 ±1	130 ±10	190 ±0	61 ±2	150 ±0	110 ±0	130 ±0	63 ±3	64 ±2

Table 7.3. (Continued) Metals associated with hillslope source material and fire-related bed sediments in Strontia Springs Reservoir

	Buffalo River Standard		Hillslope Source Material				Delta		Strontia Springs Core 4B			
			Buffalo Creek			Spring Creek						
	Observed	Certified	Un-burned soil	Burned soil	Burned eroded silt	Ash	0.6-1.2 m below surface	1.5-1.6 m below surface	0.02-0.04 m below surface	0.50-0.52 m below surface	0.09-0.92m below surface	1.06-1.08 m below surface
Pr	5.7 ±0.8	na	7 ±0	21 ±0	22 ±0	7 ±0	18 ±0	18 ±0	35 ±1	36 ±1	21 ±0	20 ±1
Rb	57 ±21	100	62 ±1	130 ±10	37 ±2	63 ±0	74 ±1	39 ±0	64 ±2	24 ±0	38 ±1	69 ±1
Sb	3.9 ±0.3	3.79 ±0.15	0.9 ±0.1	<0.8 ±0.0	1.0 ±0.1	1.7 ±0.1	<0.8 ±0.1	1.3 ±0.0	1.0 ±0.1	1.1 ±0.1	<0.8 ±0.0	0.8 ±0.1
Se	5 ±1	1.12 ±0.05	5 ±1	5 ±1	4 ±0	5 ±1	5 ±0	4 ±1	7 ±1	6 ±1	6 ±1	4 ±1
SiO_2	665000 ±66000	622000 ±3000	640000 ±0	600000 ±0	560000 ±10000	280000 ±10000	690000 ±0	530000 ±10000	540000 ±10000	510000 ±10000	610000 ±10000	340000 ±0
Sm	5.6 ±0.6	6.7	6 ±0	18 ±1	16 ±0	6 ±0	18 ±0	14 ±0	29 ±0	30 ±0	20 ±0	17 ±0
Sr	120 ±9	130	94 ±2	110 ±0	95 ±2	950 ±20	96 ±1	120 ±0	120 ±0	80 ±1	83 ±0	110 ±0
Tb	0.8 ±0.1	na	0.8 ±0.0	2.7 ±0.0	2.0 ±0.0	0.8 ±0.0	2.6 ±0.1	1.8 ±0.1	3.6 ±0.0	3.8 ±0.0	2.7 ±0.1	2.1 ±0.0
Te	0.2 ±0.1	na	0.3 ±0.1	0.1 ±0.1	0.2 ±0.0	0.4 ±0.1	0.2 ±0.1	0.2 ±0.1	0.3 ±0.0	0.4 ±0.1	0.2 ±0.0	0.1 ±0.1
Th	7.9 ±0.9	9.2	14 ±0	53 ±2	36 ±0	8.4 ±0.1	17 ±0	17 ±0	38 ±0	40 ±0	28 ±1	16 ±0
Ti	4570 ±130	4570 ±180	7400 ±0	11000 ±0	5500 ±0	2100 ±100	6400 ±0	4900 ±0	6400 ±0	6500 ±0	6600 ±0	3400 ±0
Tl	1.00 ±0.05	1.06 ±0.07	0.88 ±0.02	1.00 ±0.00	0.89 ±0.02	0.50 ±0.02	0.98 ±0.03	0.72 ±0.02	1.10 ±0.00	1.10 ±0.00	0.86 ±0.02	0.51 ±0.03
Tm	0.3 ±0.0	na	0.6 ±0.0	2.2 ±0.0	1.0 ±0.0	0.4 ±0.0	1.4 ±0.1	0.9 ±0.0	1.6 ±0.1	1.6 ±0.0	1.4 ±0.0	1.0 ±0.0
U	3.2 ±0.1	3.13 ±0.13	5.5 ±0.0	9.1 ±0.1	6.1 ±0.0	2.2 ±0.1	8.3 ±0.0	9.7 ±0.4	9.1 ±0.0	11.0 ±0.0	7.0 ±0.1	7.2 ±0.0
V	90 ±3	95 ±4	54 ±1	44 ±0	44 ±1	34 ±2	36 ±0	41 ±1	56 ±1	60 ±1	45 ±2	25 ±1
W	3.3 ±0.4	na	4.2 ±0.2	4.8 ±0.4	3.5 ±0.2	3.8 ±0.2	3.4 ±0.0	2.8 ±0.2	5.3 ±0.2	5.3 ±0.4	4.1 ±0.2	2.1 ±0.1
Y	20 ±2	na	24 ±0	89 ±3	49 ±0	23 ±0	65 ±0	48 ±1	89 ±2	91 ±0	70 ±0	55 ±0
Yb	2.6 ±0.2	2.8	6 ±0	17 ±0	8 ±0	2 ±0	10 ±0	7 ±0	12 ±0	12 ±0	10 ±0	7 ±0
Zn	442 ±15	438 ±12	480 ±10	200 ±10	280 ±0	230 ±0	270 ±0	290 ±10	470 ±10	360 ±0	240 ±10	230 ±10
Zr	354 ±42	300	1000 ±10	1300 ±0	580 ±0	140 ±0	1300 ±0	430 ±10	390 ±0	330 ±0	950 ±10	440 ±10

[a]Analytical procedures were rechecked and these values are correct but possible contamination during sampling would require additional analysis of replicate samples to verify these values.

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Appendices

Appendix 1. Format of rill files

[Data are on the accompanying CD in directory Rill. Data file names have the form rnnXmmmm.dat, where rnn is the survey number; X stands for A, B, or C; and mmmm is the cross-section number; the value of mmmm is listed under the Rill column in this table. In the data file, column 1 is the distance from center of left bank pin in meters; column 2 is the arbitrary elevation in meters]

Survey number	Date	Days after 4 June 1998	Rill		
			A	B	C
			1998		
r01	4 June	0	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
r02	5 August	62	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
r03	21 & 27 October	139, 146	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
			1999		
r04	5 May	335	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
r05	30 July[a]	421	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
			2000		
r06	30 May	725	0000	0400	1000
			0100	0500	1100
			0200	0600	1200
			0300	0700	1300
			0400	0800	1400
r07	19 November	898	0100	0500	1100
			0200	0600	1200
			0300	0700	1300

[a]Data were collected after an intense rainstorm on 17 July 1999 with 30-minute intensity of 15-18 mm/h.

Appendix 2. Coordinates and elevation of reference pins for cross sections of rills on a south-facing hillslope in the Spring Creek watershed

[Numbers below **Cross section** are distance of the cross section downstream from the beginning of the rill; the arbitrary coordinates and elevation given here can be converted to UTM coordinates and elevation above sea level by using eq. 5.1-5.3; m, meter]

Rill	Cross section	Left bank pin			Right bank pin		
		North (m)	East (m)	Elevation (m)	North (m)	East (m)	Elevation (m)
Rill-BM1	1/2-inch rebar	5257.766	3933.390	2100.331	4360511.747[a]	484059.928[a]	1979.738[a]
A	0000	used just the prism and no rod and could not see these left bank pins			5247.034	3942.090	2097.289
	0100				5246.173	3942.520	2097.023
	0200	5245.362	3943.697	2096.686	5245.248	3942.662	2096.690
	0300	5244.394	3943.817	2096.310	5244.292	3942.763	2096.310
	0400	5243.471	3943.930	2095.958	5243.336	3942.880	2095.957
B	0400	5234.046	3950.352	2091.877	5233.981	3949.344	2091.881
	0500	5233.108	3950.360	2091.458	5233.092	3949.365	2091.456
	0600	5232.154	3950.331	2091.003	5232.188	3949.327	2091.007
	0700	5231.249	3950.297	2090.616	5231.196	3949.272	2090.605
	0800	5230.336	3950.346	2090.189	5230.337	3949.311	2090.197
C	1000	5221.694	3953.370	2085.534	5221.457	3952.415	2085.523
	1100	5220.821	3953.585	2085.114	5220.609	3952.620	2085.115
	1200	5220.023	3953.557	2084.659	5219.680	3952.612	2084.659
	1300	5219.103	3953.972	2084.143	5218.874	3952.862	2084.145
	1400	5218.283	3954.236	2083.672	5218.011	3953.106	2083.676

[a]For this single reference pin, the values for the left bank pin are the arbitrary coordinates and the values for the right bank are the UTM coordinates

Appendix 3. Summary of stereo photographs for the two watersheds burned by the Buffalo Creek Fire

[Unless otherwise noted, the U.S. Geological Survey has the photographs]

Date	Scale	Location	Type	Comment
2 June 1996	1:12,000	Buffalo Creek	Color	U.S. Forest Service has the film and U. S. Geological Survey has prints and some diapositives.
2 June 1996	1:12,000	Spring Creek	Color	
2 & 5 August 1996	1:12,000	Buffalo Creek	Color	U.S. Forest Service has the film and U. S. Geological Survey has prints and some diapositives.
2&5 August 1996	1:12,000	Spring Creek	Color	
1 June 1997	1:3,000	Buffalo Creek	Color	Five photos upstream from the mouth were centered over the main channel.
1 June 1997	1:3,000	Spring Creek	Color	Six photos upstream from the mouth were centered over the main channel.
17 July 1997	1:3,000	Buffalo Creek	Color	Three photos upstream from the mouth were centered over the main channel.
17 July 1997	1:3,000	Spring Creek	Color	Seven photos upstream from the mouth were centered over the main channel.
8 August 1997	1:3,000	Buffalo Creek	Color	Three photos upstream from the mouth were centered over the main channel.
8 August 1997	1:3,000	Spring Creek	Color	Seven photos upstream from the mouth were centered over the main channel.
6 September 1997	1:3,000	Buffalo Creek	Black and white	Two photos were taken at the mouth.
6 September 1997	1:3,000	Spring Creek	Black and white	Photos (44) were taken of the entire main channel and the upper tributaries.
15 October 1997	1:3,000	Spring Creek	Color	Photos (53) were taken of the entire main channel and the upper tributaries.
10 May 1998	1:3,000	Spring Creek	Black and white	Photos (53) were taken of the entire main channel and the upper tributaries. Some diapositives were made.
20 June 1998	1:3,000	Spring Creek	Color positives	Entire watershed was photographed but only with 20 percent overlap and the scale varies because of relief.
15 July 1998	1:12,000	Spring Creek	Color	Two prints and diapositives were obtained which cover the most of the watershed.
15 July 1998	1:12,000	Spring Creek	Color	Ten prints were centered over the main channel.

Appendix 4. Average arbitrary coordinates and adjustments for reference pins located at either end of cross sections in Spring Creek

[The coordinate system and elevations are arbitrary but were estimated to be close to true north, true east, and elevation above sea level. The average location of each reference pin is the average of four surveys (May-June, July, August, and September-October 1997) and the north and east adjustment are defined by the equations: average north (east) coordinate of left bank pin = survey coordinate + North adjustment (East adjustment); adjustments were interpolated for transects between the cross sections in this table; left bank (LB) and right bank (RB) are defined facing downstream; ns, not resurveyed; bs, backsight; na, does not apply because automatic level, metric tape, and surveying rod method were used; m, meter]

Cross section and bank		Average coordinate			North adjustment (m)							East adjustment (m)						
		North N (m)	East E (m)	Elevation Z (m)	May-June 1997	July 1997	Aug. 1997	Sept.-Oct. 1997	April May 1998	19-21 May 1998	1-2 July 1998	May-June 1997	July 1997	Aug. 1997	Sept.-Oct. 1997	April May 1998	19-21 May 1998	1-2 July 1998
-2.7	-10m	4695.88	5215.63	1996.30	installed later		-0.00	0.00	-0.02	ns	ns	installed later		0.02	-0.02	-0.02	ns	ns
-2.7	RB	4660.79	5179.25	1996.78	0.00	-0.03	bs		-0.02	0.01	ns	bs		0.00	0.00	-0.02	-0.02	ns
100	LB	4791.02	5186.29	2000.48	-0.01	0.01	0.01	0.00	-0.04	0.01	-0.08	-0.04	0.01	0.01	0.02	0.00	-0.01	-0.12
100	RB	4775.38	5151.00	2001.16	-0.01	0.01	0.01	0.00	0.03	0.01	-0.03	-0.04	0.01	0.01	0.02	0.02	0.04	-0.08
187	LB	4871.59	5142.81	2003.84	0.06	0.01	0.00	-0.07	-0.02	bs	-0.08	-0.01	-0.06	0.00	0.05	0.09	bs	-0.12
187	RB	4848.35	5116.39	2006.14	0.06	0.01	0.00	-0.07	0.00	ns	-0.14	-0.01	-0.06	0.00	0.05	0.09	ns	-0.12
250	LB	4909.03	5096.56	2006.22	-0.01	0.02	0.04	-0.05	0.08	-0.11	-0.06	-0.06	-0.03	0.01	0.07	0.04	-0.04	-0.09
250	RB	4896.70	5066.09	2006.76	-0.01	0.02	0.04	-0.05	0.00	-0.16	-0.15	-0.06	-0.03	0.01	0.07	-0.02	-0.07	-0.16
341	LB	4995.62	5049.64	2010.09	-0.08	0.03	0.09	-0.04	0.04	-0.11	-0.13	-0.10	0.00	0.02	0.08	-0.04	-0.07	-0.17
341	RB	4963.15	5018.87	2010.18	-0.08	0.03	0.09	-0.04	0.05	-0.15	-0.14	-0.10	0.00	0.02	0.08	-0.05	-0.07	-0.21
393	LB	5025.31	4997.55	2010.98	-0.10	0.03	0.10	-0.03	0.01	-0.16	-0.22	-0.12	-0.03	0.04	0.11	0.00	-0.07	-0.15
393	RB	4988.59	4980.54	2012.49	-0.10	0.03	0.10	-0.03	0.01	-0.13	-0.16	-0.12	-0.03	0.04	0.11	-0.04	0.00	-0.17
483	LB	5062.91	4921.61	2014.78	-0.11	-0.02	0.14	-0.01	0.05	-0.10	-0.14	-0.17	-0.03	0.03	0.18	0.00	0.03	-0.15
483	RB	5029.25	4893.57	2016.12	-0.11	-0.02	0.14	-0.01	0.08	-0.08	ns	-0.17	-0.03	0.03	0.18	0.01	0.02	ns
567	LB	5109.73	4841.46	2017.83	-0.18	-0.05	0.18	0.05	ns	-0.03	-0.13	-0.20	-0.06	0.03	0.23	ns	0.02	-0.15
567	RB	5076.78	4836.36	2019.34	-0.18	-0.05	0.18	0.05	0.08	0.02	-0.14	-0.20	-0.06	0.03	0.23	0.04	0.01	-0.16
679	LB	5121.81	4741.22	2022.27	-0.27	-0.08	0.22	0.14	-0.10	-0.15	na	-0.26	-0.10	0.05	0.32	-0.01	-0.08	na
679	RB	5104.92	4723.55	2023.81	-0.27	-0.08	0.22	0.14	-0.14	ns	na	-0.26	-0.10	0.05	0.32	-0.03	ns	
755	LB	5149.84	4666.00	2027.26	-0.28	-0.15	0.23	0.20	-0.07	-0.09	na	-0.26	-0.13	0.05	0.33	-0.05	-0.04	na
755	RB	5117.17	4656.22	2026.69	-0.28	-0.15	0.23	0.20	-0.08	-0.03	na	-0.26	-0.13	0.05	0.33	0.01	-0.07	na
815	LB	5162.67	4609.94	2029.31	-0.28	-0.17	0.22	0.23	-0.15	-0.12	na	-0.31	-0.13	0.06	0.38	-0.01	-0.09	na
815	RB	5138.82	4601.54	2030.03	-0.28	-0.17	0.22	0.23	-0.15	-0.08	na	-0.31	-0.13	0.06	0.38	0.05	-0.09	na
905	LB	5196.49	4521.06	2031.42	-0.33	-0.19	0.26	0.26	-0.09	-0.11	na	-0.16	-0.21	0.04	0.33	-0.14	-0.15	na
905	RB	5171.73	4524.04	2032.86	-0.33	-0.19	0.26	0.26	-0.09	-0.12	na	-0.16	-0.21	0.04	0.33	-0.12	-0.14	na
1006	LB	5195.30	4422.50	2035.75	-0.40	-0.19	0.25	0.34	-0.10	-0.13	na	-0.18	-0.22	0.03	0.36	-0.09	-0.13	na
1006	RB	5176.79	4420.09	2035.88	-0.40	-0.19	0.25	0.34	-0.06	-0.08	na	-0.18	-0.22	0.03	0.36	-0.04	-0.10	na
1200	LB	5248.49	4236.05	2043.06	-0.38	-0.29	0.16	0.54	-0.05	-0.05	na	-0.18	-0.27	0.01	0.45	-0.16	-0.15	na
1200	RB	5224.36	4234.47	2043.33	-0.38	-0.29	0.16	0.54	-0.04	-0.04	na	-0.18	-0.27	0.01	0.45	-0.04	-0.04	na
1340	LB	5219.33	4099.82	2050.06	-0.42	-0.35	0.10	0.67	-0.07	-0.07	na	-0.19	-0.30	-0.01	0.50	-0.05	-0.02	na
1340	RB	5203.42	4101.10	2049.66	-0.42	-0.35	0.10	0.67	-0.04	-0.04	na	-0.19	-0.30	-0.01	0.50	-0.04	-0.04	na
1450	LB	5182.56	3994.26	2056.34	This reference pin was not in place until May 1998, so no adjustments are necessary.													
1450	RB	5167.17	4000.22	2056.64	This reference pin was not in place until May 1998, so no adjustments are necessary.													

Appendix 5. Average arbitrary coordinates and adjustments for reference pins located at either end of cross sections in Buffalo Creek

[The coordinate system and elevations are arbitrary and they are not the same as those in Spring Creek. They were estimated to be close to true north, true east, and elevation above sea level. The average location of each reference pin is the average of four surveys (June and July 1997) and the north and east adjustment are defined by the equations: average north (east) coordinate of left bank pin = survey coordinate + North adjustment (East adjustment); adjustments were interpolated for transects between the cross sections in this table; left bank (LB) and right bank (RB) are defined facing downstream; ns, not resurveyed; bs, backsight; m, meter]

Cross section and bank		Average coordinate			North adjustment (m)				East adjustment (m)			
		North N (m)	East E (m)	Elevation Z (m)	June 1997	July 1997	August 1997	May 1998	June 1997	July 1997	August 1997	May 1998
10	LB	5075.18	4981.93	1999.83	0.02	-0.02	-0.01	bs	-0.01	0.01	-0.34	bs
10	RB	5069.41	5033.23	2001.19	0.08	-0.08	0.26	0.07	-0.05	0.06	-0.35	-0.06
79	LB	5005.03	4981.31	2000.76	0.04	-0.04	-0.11	0.06	-0.02	0.02	-0.02	-0.01
79	RB	5004.55	5023.87	2000.74	0.04	-0.04	0.19	0.07	-0.01	0.01	-0.02	-0.04
150	LB	4944.18	4961.33	2001.75	0.02	-0.02	-0.19	0.04	-0.04	0.04	0.22	-0.06
150	RB	4928.40	5005.22	2002.09	0.06	-0.06	0.08	0.10	-0.01	0.01	0.32	-0.03
230	LB	4869.27	4935.03	2004.12	-0.01	0.01	-0.33	0.00	0.01	-0.01	0.67	0.08
230	RB	4854.64	4974.67	2004.82	-0.01	0.01	-0.12	0.04	0.01	-0.01	0.72	0.05
300	LB	4798.48	4922.52	2005.03	-0.01	0.01	-0.39	0.00	-0.02	0.02	0.98	0.12
300	RB	4790.44	4951.17	2006.25	-0.01	0.01	-0.26	0.02	0.00	0.00	1.00	0.10
391	LB	4709.98	4899.26	2006.65	-0.01	0.01	-0.52	0.00	-0.05	0.05	1.35	0.12
391	RB	4702.06	4939.00	2007.43	-0.02	0.02	-0.36	0.02	-0.03	0.03	1.38	0.10
480	LB	4622.49	4888.95	2007.14	-0.04	0.04	ns	-0.01	-0.06	0.06	ns	0.10
480	RB	4612.52	4930.61	2007.74	-0.05	0.05	-0.41	0.02	-0.06	0.06	1.61	0.06

Appendix 6. UTM coordinates and arbitrary coordinates for selected reference pins near the mouth of Spring Creek

[The arbitrary coordinate system was estimated to be close to true north, true east, and elevation above sea level. GPS data were collected using a survey grade system (Trimble 4700 Rover and 4800 Base); reference pins are 4-foot long pieces of 1/2-inch rebar driven into the ground at least 0.6 meter and usually 1.0 meter; m, meter]

Cross section	Arbitrary coordinate			UTM coordinate			Elevation difference (m)	Comments
	North N (m)	East E (m)	Elevation Z (m)	North N' (m)	East E' (m)	Elevation Z' (m)		
--2.7	4695.885	5215.626	1996.297	4360010.739	485365.690	1875.181	121.116	Top of the reference pin at station -10 m located on the left bank about 4 m upstream from a boulder about 4 m in diameter. The pin is tall and the elevation less certain so it was not used to calculate the transformation between the arbitrary coordinate system and the UTM coordinate system. .
100	4775.384	5150.998	2001.160	4360087.168 4360087.126	485297.541 485297.677	1880.114 1880.096	121.055	Two measurements were made on the top of the right bank reference pin. The elevation is the average of the two measurements.
755	5149.844	4666.000	2027.258	4360438.416	484796.199	1906.622	120.636	Top of the left bank reference pin, which is on the stream side of a 1.5-2 m diameter boulder about 10 m from the left edge of the channel.
905	5196.494	4521.065	2031.424	4360478.127	484649.517	1910.801	120.623	Top of the left bank reference pin, which is in a clump of willows at the base of the rock valley wall on the left edge of the channel.
905	5171.730	4524.036	2032.861	4360453.683	484653.520	1912.291	120.570	Top of the right bank reference pin, which is about 6 m from the right valley edge up in some vegetation.
Rill-BM1	5257.766	3933.390	2100.331	4360511.747	484059.928	1979.738	120.593	On top of a knoll above where the south-facing hillslope traps were located opposite the site of the U. S. Geological Survey stream gage house. This reference pin is about 0.1 m above the ground.
1200	5248.487	4236.054	2043.055	4360516.626	484362.541	1921.828	121.227	Top of the left bank reference pin, which is 0.3-0.4 m above the ground and near a rock outcrop along the left valley edge. It is about 25 m downstream from a relatively large tributary on the left bank. The pin is tall and the elevation less certain so it was not used to calculate the transformation between the arbitrary coordinate system and the UTM coordinate system.
1200	5224.360	4234.472	2043.329	4360492.570	484361.890	1922.719	120.610	Top of the right bank reference pin, which is about 0.2-0.3 m above the ground near the right valley edge in a sand and gravel terrace.

Appendix 7. UTM coordinates for cross-section end points in Spring Creek

[The arbitrary coordinate system was estimated to be close to true north, true east, and elevation above sea level. UTM coordinates were computed using eqs. 5.1-5.3 in the text which are accurate to the nearest 0.1 m in horizontal directions and 0.01 m in elevation; LB, left bank; RB, right bank; pins are 4-foot long pieces of 1/2-inch rebar driven into the ground at least 0.6 m and usually 1.0 m; m, meter]

Cross section	Bank	Station (m)	Marker	UTM coordinates North (m)	East (m)	Elevation (m)
-20	LB	0.0	pin	4360003.2	485383.4	1875.07
-20	RB	72.8	pin	4359959.0	485329.6	1875.18
-2.7	LB	-35.0	pin[1]	4360029.0	485382.8	1879.26
-2.7	RB	40.5	pin	4359974.1	485331.1	1876.00
30	LB	0.0	pin	4360038.9	485359.5	1877.16
30	RB	43.8	nail	4360022.5	485318.9	1879.31
50	LB	0.0	pin	4360052.6	485340.9	1877.05
50	RB	28.8	pin	4360042.9	485313.8	1877.84
70	LB	0.0	nail	4360072.7	485341.5	1878.48
70	RB	38.1	nail	4360060.9	485306.2	1878.75
100	LB	0.0	pin	4360104.4	485332.1	1879.45
100	RB	38.7	pin	4360087.2	485297.6	1880.16
140	LB	0.0	pin	4360139.5	485313.7	1880.53
140	RB	32.0	pin	4360125.4	485284.9	1880.27
160	LB	0.0	nail	4360158.8	485299.2	1881.39
160	RB	29.4	nail	4360140.2	485276.4	1881.17
187	LB	0.0	pin	4360182.8	485284.9	1882.76
187	RB	35.3	pin	4360158.4	485259.7	1884.31
220	LB	0.0	nail	4360202.9	485258.3	1883.80
220	RB	32.0	nail	4360181.0	485234.8	1883.43
250	LB	0.0	pin	4360218.0	485237.0	1885.38
250	RB	32.9	pin	4360204.3	485207.2	1885.89
280	LB	0.0	pin	4360245.9	485219.2	1886.78
280	RB	36.4	pin	4360223.4	485190.4	1885.89
310	LB	0.0	nail	4360274.6	485198.4	1887.48
310	RB	36.9	pin	4360243.2	485178.9	1886.94
341	LB	0.0	pin	4360302.3	485186.2	1889.23
341	RB	44.9	pin	4360268.4	485157.0	1889.29
370	LB	0.0	pin+nail	4360316.7	485158.2	1889.60
370	RB	43.0	nail	4360281.5	485133.4	1889.38
393	LB	0.0	pin	4360329.5	485132.8	1890.13
393	RB	40.5	nail	4360292.0	485117.5	1891.55
423	LB	0.0	pin	4360337.8	485104.7	1891.65
423	RB	36.9	nail	4360304.1	485089.8	1891.68
453	LB	0.0	pin[2]	4360349.2	485078.4	1892.57
453	RB	38.2	pin[2]	4360316.2	485059.8	1892.67
483	LB	0.0	pin	4360363.5	485055.3	1894.14
483	RB	43.8	pin	4360328.6	485028.8	1895.25
510	LB	0.0	nai	4360382.7	485034.3	1895.19
510	RB	41.2	pin	4360351.5	485009.4	1895.42
540	LB	0.0	pin	4360403.6	485006.4	1898.19
540	RB	41.4	pin	4360365.9	484989.1	1896.96

Appendix 7. (Continued) UTM coordinates for cross-section end points in Spring Creek

Cross section	Bank	Station (m)	Marker	UTM coordinates North (m)	East (m)	Elevation (m)
567	LB	0.0	pin	4360406.5	484973.1	1896.94
567	RB	33.5	pin	4360373.3	484969.5	1898.45
590	LB	0.0	pin	4360403.1	484947.6	1898.89
590	RB	28.0	nail	4360376.5	484949.2	1898.44
620	LB	0.0	pin	4360403.6	484919.2	1900.94
620	RB	32.8	nail	4360371.5	484918.7	1899.82
650	LB	0.0	pin	4360400.9	484893.5	1901.43
650	RB	25.3	pin	4360376.3	484882.0	1902.05
679	LB	0.0	pin[3]	4360413.8	484872.5	1901.46
679	RB	24.7	pin	4360396.2	484855.6	1902.85
698	LB	0.0	nail	4360423.7	484850.2	1903.14
698	RB	20.8	pin	4360404.6	484844.1	1903.49
715	LB	0.0	pin	4360433.8	484829.5	1904.91
715	RB	21.8	pin	4360410.8	484830.5	1904.68
735	LB	0.0	nail	4360433.5	484810.4	1905.67
735	RB	29.4	nail	4360404.6	484811.2	1904.64
755	LB	0.0	pin	4360438.3	484796.1	1906.35
755	RB	34.0	pin	4360405.2	484787.8	1905.82
785	LB	0.0	pin[4]	4360440.9	484768.1	1907.25
785	RB	27.0	nail	4360416.1	484757.6	1907.30
815	LB	0.0	pin	4360448.5	484739.5	1908.20
815	RB	25.5	pin	4360424.3	484732.2	1909.09
845	LB	0.0	nail	4360460.7	484713.1	1909.74
845	RB	27.5	pin	4360436.6	484700.1	1909.52
875	LB	0.0	pin[5]	4360468.6	484682.2	1910.05
875	RB	18.5	pin	4360451.2	484675.9	1910.50
905	LB	0.0	pin	4360478.1	484649.2	1910.55
905	RB	24.9	pin	4360453.5	484653.3	1911.94
935	LB	0.0	nail	4360479.6	484620.8	1912.78
935	RB	24.3	pin	4360455.3	484620.7	1912.61
965	LB	0.0	pin	4360476.6	484588.8	1914.63
965	RB	12.0	pin	4360454.2	484593.3	1913.55
985	LB	0.0	nail	4360474.1	484570.5	1914.60
985	RB	18.9	nail	4360455.3	484571.6	1914.11
1006	LB	0.0	pin	4360472.3	484550.9	1914.67
1006	RB	18.9	pin	4360453.8	484549.4	1914.92
1025	LB	0.0	pin	4360473.3	484532.3	1916.06
1025	RB	17.3	nail	4360456.4	484530.0	1915.72
1055	LB	0.0	pin	4360478.3	484506.9	1916.29
1055	RB	18.1	pin	4360462.5	484498.0	1916.04
1083	LB	0.0	nail	4360483.4	484475.8	1918.10
1083	RB	14.6	nail	4360469.1	484474.2	1917.60

Appendix 7. (Continued) UTM coordinates for cross-section end points in Spring Creek

Cross section	Bank	Station (m)	Marker	UTM coordinates North (m)	East (m)	Elevation (m)
1100	LB	0.0	pin	4360484.0	484459.4	1916.58
1100	RB	9.0	none	4360475.1	484457.2	1916.40
1120	LB	0.0	nail	4360489.1	484440.1	1919.78
1120	RB	12.1	nail	4360477.5	484438.0	1918.98
1150	LB	0.0	nail	4360502.0	484413.7	1921.81
1150	RB	18.6	pin	4360484.4	484407.7	1921.77
1180	LB	0.0	nail	4360512.4	484384.6	1922.16
1180	RB	19.3	pin	4360493.8	484380.2	1922.46
1200	LB	0.0	pin	4360516.7	484362.3	1922.09
1200	RB	24.2	pin	4360492.6	484361.9	1922.34
1230	LB	0.0	pin	4360509.7	484331.2	1925.09
1230	RB	19.7	pin	4360492.1	484339.2	1924.95
1260	LB	0.0	nail	4360500.0	484303.0	1926.17
1260	RB	13.9	nail	4360486.4	484307.6	1926.36
1280	LB	0.0	pin	4360496.8	484283.7	1925.98
1280	RB	14.9	pin	4360482.1	484287.9	1927.36
1300	LB	0.0	pin	4360493.9	484264.5	1927.98
1300	RB	22.2	pin	4360472.2	484269.2	1927.90
1320	LB	0.0	pin[6]	4360489.5	484246.1	1930.06
1320	RB	20.3	nail	4360469.6	484249.4	1927.83
1340	LB	-0.5	nail	4360481.3	484227.7	1929.32
1340	RB	15.5	pin	4360465.5	484229.7	1928.48
1370	LB	0.0	nail	4360467.2	484197.0	1930.00
1370	RB	9.0	nail	4360457.7	484204.1	1930.11
1410	LB	0.0	nail[7]	4360462.4	484159.0	1933.04
1410	RB	18.0	pin	4360545.1	484159.9	1932.62
1430	LB	0.0	nail[7]	4360449.5	484139.6	1933.75
1430	RB	14.0	nail	4360437.9	484147.5	1933.70
1450	LB	0.0	pin	4360439.7	484124.1	1934.97
1450	RB	16.7	nail	4360424.6	484130.7	1935.90
1470	LB	0.0	nail	4360431.4	484106.2	1936.36
1470	RB	14.0	nail	4360418.4	484111.2	1935.51

[1]The coordinates mark a high spot on bedrock which was used as a bench mark; the pin is located 2 meters beyond this point on line of section.

[2]The marker is probably a pin but could not be verified in November 2001 because it was either covered by an alluvial fan from a tributary or colluvium from the hillslope.

[3]This pin may be lost because a neighboring tree has been eroded out from the bank.

[4]This pin may be under a fallen tree or an alluvial fan from a small tributary.

[5]This pin was buried before 2000 and a yellow flag on a wire was put next to a nail located at station -1.0 but they may be too far upstream.

[6]A second pin was put in lower to help the rodman stand on the steep hillslope.

[7]These nails could not be verified in November 2001 because colluvium from the hillslope has buried them.

Appendix 8. Format of cross-section and transect files for Spring Creek

[Data are on the accompanying CD in directory SpringCreek. The directory SpringCreek has 19 subdirectories listed in the Survey column below. The data file names have the form *sNNtMMMM*.raw, or *sNNxMMMM*.raw, where s stands for Spring Creek, *NN* is the survey number, *t* stands for transect, *x* stands for cross section, *MMM* or *MMMM* is the transect or cross section number. A small 'm' means minus and 'p' represents the decimal point; surveys 060296 and 080296 have UTM coordinates and elevations above sea level with no prefix *sNN*; the other surveys have arbitrary coordinates--see Appendices 4-7]

Survey	Dates	Column in the data file					Comments
			2	3	4	5	
				Spring Creek 1996			
s060296	02 June	East (m)	North (m)	Elevation (m)	blank	blank	Measurements were made from the right-bank to the left bank using aerial photogrammetry and are in UTM coordinates. File extension is .txt not .raw.
s080296	02 August	East (m)	North (m)	Elevation (m)	blank	blank	Measurements were made from the right-bank to the left bank using aerial photogrammetry and are in UTM coordinates. File extension is .txt not .raw.
				Spring Creek 1997			
s01	29 May to 11 June	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank or blank	Transects are comma and space delimited and cross sections are space delimited.
s02	22 July to 28 July	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Files are comma delimited and some points from survey 01 were added at the beginning or end of the file.
s03	3 August to 8 August	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Files are comma delimited and some points from previous surveys were added at the beginning or end of the file.
s04a	Estimate for 31 August	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	File extension is .est and comma delimited. Used survey 04 data and essentially connected terraces on left and right banks. Shot points with number 000 are estimated values.
s04	27 September to 6 October	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Data are comma delimited. Some points from previous surveys were added at the beginning or end of the file.
				Spring Creek 1998			
s05	28 April to 3 May	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Data are comma delimited. Some points from previous surveys were added at the beginning or end of the file.
s06	19 May to 21 May	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Data are comma delimited. Some points from previous surveys were added at the beginning or end of the file.

Appendix 8. (Continued) Format of cross-section and transect files for Spring Creek

Survey	Dates	Column in the data file					Comments
			2	3	4	5	
s07	1 July to 2 July	Shot number	North (m)	East (m)	Elevation (m)	ID number or distance from left bank	Data are comma delimited. Did not survey transect -020 nor cross section -2.7 and assumed no change. Transects and cross sections from 0030 to 0640 were resurveyed.
s07	1 July to 2 July	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited. Transects and cross sections from 0679 to 1470 were resurveyed using automatic level, metric tape, and surveying rod.
s08	16 July to 17 July	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s09	5 August to 6 August	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s10	12 October to 14 October	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
				Spring Creek 1999			
s11	20 March to 21 March	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s12	16 July to 17 July	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s13	31 July to 1 August	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s14	8 November to 9 November	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
				Spring Creek 2000			
s15	13 May to 14 May	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
s16	21 October	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.

Appendix 9. Format of cross-section and transect files for Buffalo Creek

[Data are on the accompanying CD in directory BuffaloCreek. The data file names have the form *BcNNtMMM*.raw, *BcNNxMMM*.raw, *BNNtMMM*.raw, or *BNNxMMM*.raw, where *B* or *Bc* stands for Buffalo Creek, *NN* is the survey number, *t* stands for transect, *x* stands for cross section, and *MMM* or *MMMM* is the transect or cross section number; surveys have arbitrary coordinates--see Appendices 4-7]

Survey	Dates	Column in the data file					Comments
		1	2	3	4	5	
				Buffalo Creek 1997			
Bc01	12 June to 16 June	Shot number	North (m)	East (m)	Elevation (m)	ID number Some cross sections list distance from left bank	Transects are comma and space delimited and cross sections are space delimited.
Bc02	18 July to 21 July	Shot number	North (m)	East (m)	Elevation (m)	ID number Some cross sections list distance from left bank	Data are comma delimited.
Bc03	10 August to 11 August	Shot number	North (m)	East (m)	Elevation (m)	ID number Cross sections list distance from left bank	Transects are comma and space delimited and cross sections are space delimited.
				Buffalo Creek 1998			
B04	7 May to 9 May	Shot number	North (m)	East (m)	Elevation (m)	ID number Cross sections list distance from left bank	Data are comma delimited.
B05	21 July	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
B06	7 August	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
B07	17 October	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.
				Buffalo Creek 2000			
B08	4 June	Measurement number	Distance from left bank (m)	nothing just zeros	Elevation (m)	ID number	Data are space delimited.

Appendix 10. Information for erosion and deposition files for Spring and Buffalo Creeks

[Data are on accompanying CD in directory ErosionDeposition.The data files SCedarea.ext and Bcedarea.ext have 3 columns, which are sometimes delimited by commas and sometimes delimited by spaces; .ext is the file extension. In the data file column 1 is the cross section or transect ID number; column 2 is the Net erosion in m^2; and column 3 is the Net deposition in m^2. Files for Spring Creek have a prefix SC and those for Buffalo Creek have a prefix Bc; m^2, square meter]

File extension	Spring Creek	Buffalo Creek
.000	02 June 1996 -- 02 August 1996	None
.00a	02 August 1996 -- 05 June 1997	None
.001	05 June 1997 -- 25 July 1997	14 June 1997 -- 19 July 1997
.002	25 July 1997 -- 6 August 1997	19 July 1997 -- 11 August 1997
.003	6 August 1997 -- 31 August 1997	11 August 1997 -- 08 May 1998
.004	31 August 1997 -- 02 October 1997	08 May 1998 -- 21 July 1998
.005	2 October 1997 -- 01 May 1998	21 July 1998 -- 07 August 1998
.006	01 May 1998 -- 20 May 1998	07 August 1998 -- 17 October 1998
.007	20 May 1998 -- 02 July 1998	17 October 1998 -- 04 June 2000
.008	02 July 1998 -- 17 July 1998	None
.009	17 July 1998 -- 06 August 1998	None
.010	06 August 1998 -- 13 October 1998	None
.011	13 October 1998 -- 21 March 1999	None
.012	21 March 1999 -- 17 July 1999	None
.013	17 July 1999 -- 01 August 1999	None
.014	01 August 1999 -- 08 November 1999	None
.015	08 November 1999 -- 14 May 2000	None
.016	14 May 2000 -- 21 October 2000	None

Appendix 11. Formats for erosion data collected in watersheds W960 and W1165

[m, meter; cm, centimeter; m^2, square meter]

Data are on the accompanying CD in directory Watersheds.

The data are in two data files w960.dat and w1165.dat:

Column 1 = observation number
Column 2 = stream order
Column 3 = stream number
Column 4 = distance from mouth (m)
Column 5 = cumulative stream length (m)
Column 6 = top width of channel (cm)
Column 7 = bottom width of channel (cm)
Column 8 = depth of channel (cm)
Column 9 = rise of channel slope (m)
Column 10 = run of channel slope (m)
Column 11 = rise of side slope on left bank (m)
Column 12 = run of side slope on left or right bank (m)
Column 13 = roughness height (cm), 999 = not determined
Column 14 = erosion (-1) or deposition (1)

The summary data are in the ASCII files w960e.dat and w1165e.dat:

Column 1 = observation number
Column 2 = cumulative stream length above the measurement (m)
Column 3 = area of net erosion (m^2)
Column 4 = slope of the drainage channel over a distance of 1.8 meter
Column 5 = cumulative drainage area upstream from measurement section (m^2)

Appendix 12. Interpolated particle-size distribution for the bed material in Spring Creek

[See Table 6.1 for the measured values; fitted values were calculated from a cubic spline program provided by R. Stallard; phi equals $-\log_2$ (diameter in millimeters); mm, millimeter]

Particle size		Fitted values		Measured value
(phi)	(mm)	Percent per phi interval	Percent finer	Percent finer
5.0	0.032	0.67	0.76	--
4.75	0.037	0.76	0.94	--
4.50	0.044	0.86	1.15	--
4.25	0.053	0.96	1.37	--
4.00	0.062	1.07	1.63	1.6
3.75	0.074	1.17	1.91	--
3.50	0.088	1.22	2.21	--
3.25	0.105	1.24	2.52	--
3.00	0.125	1.22	2.83	2.9
2.75	0.149	1.22	3.13	--
2.50	0.177	1.29	3.44	--
2.25	0.210	1.43	3.78	--
2.0 0	0.250	1.64	4.17	4.1
1.75	0.297	1.88	4.61	--
1.50	0.354	2.09	5.10	--
1.25	0.420	2.27	5.65	--
1.00	0.500	2.43	6.24	6.4
0.75	0.595	2.69	6.87	--
0.50	0.707	3.16	7.60	--
0.25	0.841	3.84	8.47	--
0.00	1.00	4.75	9.54	9.7
-0.25	1.19	5.99	10.9	--
-0.50	1.41	7.69	12.6	--
-0.75	1.68	9.85	14.8	--
-1.00	2.00	12.5	17.5	17.2
-1.25	2.38	15.3	21.0	--
-1.50	2.83	18.1	25.2	--
-1.75	3.36	20.8	30.0	--
-2.00	4.00	23.5	35.6	34.4
-2.25	4.76	23.6	41.7	--
-2.50	5.66	25.3	48.1	--
-2.75	6.73	23.5	54.3	--
-3.00	8.00	19.9	59.7	61.3
-3.25	9.51	15.6	64.1	--
-3.50	11.3	11.9	67.6	--
-3.75	13.4	8.72	70.1	--
-4.00	16.00	6.08	72.0	72.2
-4.25	19.0	4.14	73.2	--
-4.50	22.6	3.08	74.1	--
-4.75	26.9	2.88	74.8	--
-5.00	32.0	3.55	75.6	75.1
-6.00	64.0	8.01	81.5	81.7
-7.00	128.	9.40	91.0	92.0
-8.00	256	4.09	97.6	--
-9.00	512	8.99	99.9	100.0

Appendix 13. Distances from station 15 in Strontia Springs Reservoir along the center line of the reservoir

[Station 15 is at the beginning of the reservoir and the station numbers decrease in the downstream direction; whole integer numbered stations have bench marks along the shoreline and the distance between these whole integer numbered stations was divided into ten sections and listed as a decimal value in the table below; 12/13 was a station between station 12 and station 13 and also has a bench mark; m, meter]

Station	Distance (m)	Station	Distance (m)
		11.5	815
15	0	11.4	834
14	100	11.3	853
13.9	130	11.2	872
13.8	159	11.1	891
13.7	188	11	910
13.6	218	10.9	923
13.5	248	10.8	937
13.4	277	10.7	950
13.3	306	10.6	964
13.2	336	10.5	977
13.1	366	10.4	990
13	396	10.3	1004
12/13.9	412	10.2	1017
12/13.8	429	10.1	1031
12/13.7	445	10	1044
12/13.6	462	9.9	1060
12/13.5	478	9.8	1077
12/13.4	494	9.7	1093
12/13.3	511	9.6	1110
12/13.2	527	9.5	1126
12/13.1	544	9.4	1142
12/13	560	9.3	1159
12.9	576	9.2	1175
12.8	592	9.1	1192
12.7	608	9	1208
12.6	624	8.8	1264
12.5	640	8.6	1320
12.4	656	8.4	1376
12.3	672	8.2	1432
12.2	688	8.0	1488
12.1	704	7.8	1515
12	720	7.6	1543
11.9	739	7.4	1570
11.8	758	7.2	1598
11.7	777	7	1625
11.6	796		

Appendix 14. Longitudinal bathymetric surveys of Strontia Springs Reservoir

[Data are on the accompanying CD in directory StrontiaSprings. Station, Denver Water Department's bench marks located on each side of the reservoir; File is the name of the data file on the CD. In the data files, the format is column 1 equals the distance from station 15 in meters, column 2 equals the depth in feet, column 3 equals the distance from station 15 in feet, and column 4 equals the elevation above sea level in feet.]

Survey number	Date	Water level (feet)	Station Beginning to Ending	File	Comments
			1993		
0	1993	unknown	not applicable	S1993.dat[a]	Pre-fire elevations at 9 locations along the center line of the reservoir.
			1996		
1	13 September	5995.6	7 to 13.3	S13sep96.dat	
11	23 September	not measured	12 to 13	STopgrvl.dat[a]	Elevations at the top of the gravel layer.
12	23 September	not measured	12 to 13	STopblck.dat[a]	Elevations at the top of the black layer.
13	23 September	not measured	12 to 13	SBotblck.dat[a]	Elevations at the bottom of the black layer.
2	2 October	5996.0	7 to 14.5	S02oct96.dat	
			1997		
3	27 June	5996.84	7 to 14	S27jun97.dat	
4	13 August	5994.9	10 to 14	S13aug97.dat	
5	12 September	5992.6	7 to 13.9	S12sep97.dat	
			1998		
6	22 May	5993.1	8 to 14	S22may98.dat	
7	15 July	5987.8	8 to 12.2	S15jul98.dat	Water was too shallow to reach upstream of station 12.2.
8	3 August	5991.75	7 to 12/13	S03aug98.dat	Water depth was measured with an oar.
9	23 October	5998.76	7 to 14	S23oct98.dat	
			1999		
10	4 June	6003.7	7 to 14	S04jun99.dat[a]	Estimated depths were from stations 7 to 9.

[a] Column 2 equals the elevation above sea level in feet and colums 3 and 4 are blank.