Suspended Sediment in the Rivers of Northern Yellowstone

Assessing Changes from the 1988 Fires

by Roy Ewing

"How on earth did I get here? Is this really worth it? This is crazy." I remember 1 a.m. on a cold night in early June 1986. The Lamar River was swollen with water that had melted from the winter snowpack and picked up a lot of mud on the way down the watershed. My supervisor, park hydrologist Jana Mohrman, and I were suspended over the river in an aluminum car that rode on a thick steel cable just below the canyon downstream of Slough Creek. Through the snow that blew intermittently, I could see the heavy brass water sampler—also known as the "fish"—as it fell toward the roaring river below. As it plunged into the river, the swift current carried it downstream, jerking the little cable car down and tilting everything off vertical. We steadily winched the fish down until it touched the river bottom and then cranked it back up. As we hoisted in the swaying sampler and retrieved the glass pint bottle, the cable car was freed from the currents and bounced around wildly. I recall loading another bottle into the sampler, keeping an eye peeled for floating logs coming down the river, and wondering how I got into this situation.

That late-night river sampling was part of a study to identify major sediment-producing tributary watersheds in the northern portion of Yellowstone National Park, including the Yellowstone and Lamar rivers (Fig. 1). Our research began in 1985, in response to the concerns of the Livingston (Montana) chapter of Trout Unlimited. Local anglers and businesses dependent on river activities were concerned about the levels of suspended sediment in these rivers. The sediment carried by a river can endanger fish populations by smothering spawning beds and reducing the supply of aquatic invertebrates on which fish feed. The periodic debate over the level of ungulate grazing on Yellowstone's northern range prompted concerns about high levels of erosion in the park as a source of this sediment.

An ad-hoc consulting committee that included representatives from the Montana Water Resources Division of the U.S. Geological Survey (USGS), the Snow Survey branch of the Soil Conservation Service, the Gallatin National Forest, the Montana Department of Fish, Wildlife and Parks, the Montana Water Quality Bureau, the Park County (Montana) Conservation District, and Trout Unlimited recommended a study to obtain baseline information on suspended sediment and other properties of the Yellowstone River and several of its tributaries. In addition to identifying major sediment-producing watersheds, sampling the Yellowstone and Lamar rivers over time would establish a benchmark for comparison for future studies to determine whether suspended sediment transport from the park was changing. The study was directed by the Fisheries Assistance Office of the U.S. Fish and Wildlife Service, which at that time conducted aquatic monitoring programs for Yellowstone National Park. From 1985 to 1992 researchers could be seen sampling the Yellowstone River from the Corwin Springs bridge and the Lamar River near its confluence with the Yellowstone.

How Rivers Carry Sediment

Generally, rivers carry the most suspended sediment when they receive the most runoff from their watersheds. In this northern Rocky Mountain region, this occurs during spring when the snowpack melts, rains fall, and the rivers flow at the highest streamflow levels of the year. Depending on the nature of the snowmelt season, rivers are turbid or murky from suspended sediment from April to July. From July on, the rivers become clearer

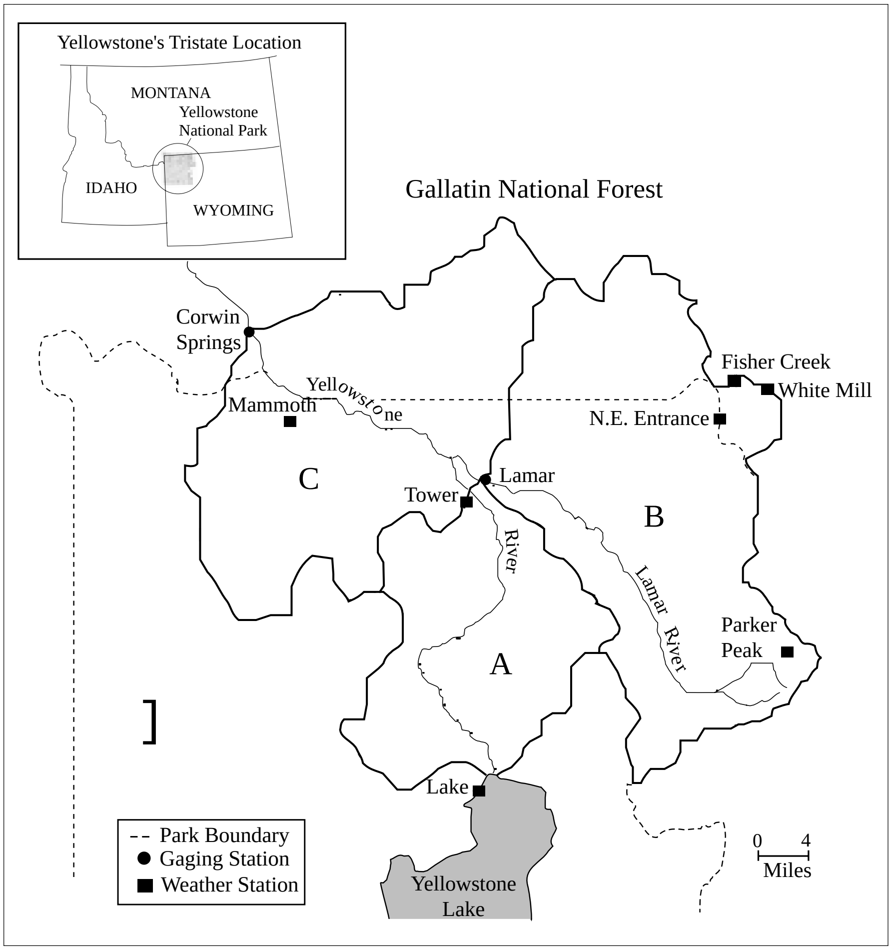

Figure 1. Study area in northern Yellowstone National Park, the Gallatin National Forest, and private lands in Montana. Study drainage subareas include: A. Yellowstone River from Yellowstone Lake to Lamar River; B. Lamar River Basin; and C. the Yellowstone River from the Lamar River to Corwin Springs, Montana.

and the level or stage of streams continuously falls until the next year's snowmelt. Periodic summer rainstorms cause runoff that carries sediment to the streams, and this intense, concentrated precipitation on a watershed can erode more sediment than snowmelt waters due to the impact of rain drops or hail. Thus, rivers in this region can get even muddier during summer than in spring, although less sediment is carried because rainstorms don't contribute as much runoff as does the snowmelt.

Other factors influence the amount of erosion and sediment transport in a watershed. The nature of the bedrock and soils is important, with soft rocks (such as shales) and unconsolidated sediments (such as prehistoric lake sediments) eroding most easily. Bedrock and soil also influence the vegetation present in a watershed. Vegetation intercepts rainfall, reducing the impact of raindrops on the soil surface, and also binds the soil with root networks. When vegetation is removed, as during construction of buildings and roads, erosion of sediment into streams is increased; most states require sediment control barriers and procedures to reduce this impact.

Rivers carry sediment in two ways: as bed load and suspended load. If you think of the river as a mode of transport, it carries a load like a truck or train. Heavier sand, gravel, pebbles, and cobbles are rolled or bounced along the river bottom during periods of high flow. This sediment, referred to as the "bed load" of the river, is difficult to measure. The lighter, individual mineral grains of sediment that produce the muddy water we see in rivers during snowmelt or after rainstorms is known as the "suspended load." It is sampled using the previously mentioned brass sampler operated from a bridge or cableway over the river.

Suspended sediment can vary greatly in space and time. Several procedures must be followed to obtain representative estimates of the sediment being carried in a river at any given time. Multiple samples are taken across the width of the river to establish a coefficient or multiplier to adjust daily samples taken at a single point. During the spring thaw, snow melts faster as each day warms up; a maximum melt rate occurs at about 3 p.m., after which the melt rate declines. This produces a diurnal surge of water and sediment that may take some time to reach the sampling station. Sediment sampling may therefore have to occur at odd hours in order to obtain representative samples of the daily sediment transport. The same is true for sediment plumes from summer thunderstorms—the afternoon storm plume may not reach the sampling station for hours or days. To adjust for yearly variations in runoff, sediment must be sampled during both low and high precipitation years.

Variations in precipitation and snowmelt from 1985 to 1987 caused the Yellowstone River to carry widely varying amounts of runoff (volume of water). In 1985, the runoff at Corwin Springs was 78 percent of the long-term average (1961-1988), while the warm spring of 1986 resulted in a large snowmelt runoff and overall runoff that was 116 percent of the average. In 1987, a near-drought resulted in runoff that was just 56 percent of the average. These variations enabled us to sample suspended sediment during low, moderate, and high flow years and obtain a good estimate of the relationship between streamflow and suspended sediment. As it happened, the drought of 1987 extended through 1988, contributing substantially to the record fires experienced throughout the ecosystem.

After the 1988 Fires

As the smoke from the 1988 fires cleared, resource managers needed to assess the dramatic changes that had taken place in Yellowstone, including those in aquatic ecosystems. Many studies have found that several factors cause suspended river sediment to increase in burned watersheds: raindrop impact on the soil increases because the tree canopy that intercepted raindrops is reduced or gone; surface flow increases because of groundcover destruction; and sediment delivery patterns change. Because increased suspended sediment may harm fish populations, we decided to continue our studies and estimate changes in suspended sediment output from the Yellowstone River drainage after the wildfires. The objectives of the extended study, which lasted from 1989 through 1992, were to measure postfire streamflow and suspended sediment on the Yellowstone and several tributaries at the same places as in our original study, and to identify fire-related changes in river sediment. Volunteers from the Student Conservation Association assisted park staff in sampling rivers and gathering hydrologic information. The National Park Service (NPS) and USGS used the same techniques used in our prefire study to collect water samples, measure streamflow, and analyze the data.

Postfire Changes in Precipitation, Runoff, and Suspended Sediment

As it happened, average total precipitation was greater during the postfire study period (1989-1992) than it was from 1985 to 1987. Although this was also true for postfire winter and spring averages, summer precipitation was less than the prefire average. Although the years after the fires had greater average precipitation than in the prefire period, cooler snowmelt periods resulted in lower streamflows. The largest postfire snowmelt runoff (116 percent of average) and total April-September runoff (102 percent of average) on the Yellowstone River at Corwin Springs occurred in 1991 (see Table 1). In contrast, the greatest streamflow prefire year, 1986, had a snowmelt runoff of 126 percent and total runoff of 116 percent of the long-term average.

Suspended sediment increased in the Yellowstone and Lamar rivers following the 1988 wildfires. The question that arose was "How much of this increase was due to greater precipitation and runoff (climatic factors) and how much was due to fire-related effects, such as increased erosion?" The postfire average total suspended sediment load increased 69 percent over the prefire average for the Yellowstone River and 34 percent for the Lamar River (see Table 2). The postfire snowmelt average load was 74 percent greater than prefire on the Yellowstone River but only 23 percent greater on the Lamar River. The Lamar River experienced much greater increases in summer sediment load (743 percent over prefire) than did the Yellowstone River (16 percent over prefire).

Fire-Related Changes in Sediment

Because greater precipitation and resultant runoff during the postfire period was likely to have caused higher levels of suspended sediment, two methods were used to try to isolate the changes in suspended sediment due to fire effects. In the first method, suggested by USGS hydrologist John Lambing, the monthly measured load (in tons) was divided by the monthly measured runoff (in acre-feet) to express the suspended sediment load as an amount per monthly runoff (tons per acre-feet). The resulting measures for postfire and prefire periods were therefore independent of river flow (or precipitation) and could be compared. Using this method, changes in river sediment could be identified that were most likely related to fire effects.

For the Yellowstone River as measured at Corwin Springs, postfire increases in monthly sediment load- per- unit- runoff occurred most notably during the snowmelt months of April, May, and June, when the postfire monthly average (1989-1992) increased 156, 105, and 42 percent over the prefire (1985-1987) monthly average values. Summer postfire changes were more variable, with the July postfire average less than prefire (-1 percent), August postfire average 100 percent greater than prefire, and the September postfire average 20 percent more than the prefire. The Lamar River, on the

Table 1. Prefire 1985-1987 and postfire 1989-1992 monthly and seasonal runoff as a percentage of long-term prefire mean runoff of the Yellowstone River at Corwin Springs, Montana.

Prefire	April	May	June	Snowmelt	July	August	Sept	Summer	April-Sept Total
1985	118.20	126.77	63.56	87.07	53.92	72.04	85.46	63.70	77.65
1986	155.10	105.52	132.14	125.69	94.70	109.09	111.96	101.23	115.83
1987	140.62	94.17	38.68	63.36	39.43	53.87	56.93	46.02	56.37
Mean	137.97	108.82	78.13	92.04	62.68	78.33	84.78	70.32	83.29
Postfire									
1989	161.08	136.47	83.90	105.83	70.11	78.56	77.61	73.53	92.82
1990	242.26	91.17	86.95	99.88	79.66	84.98	85.54	82.00	92.67
1991	96.56	138.20	107.30	115.99	76.90	83.92	88.28	80.55	101.71
1992	194.08	147.48	58.29	95.86	63.36	66.96	75.61	66.25	83.93
Mean	173.49	128.33	84.11	104.39	72.51	78.61	81.76	75.58	92.78

Table 2. Mean monthly and total suspended sediment load of runoff for the Yellowstone River and the Lamar River for the postfire (1989-1992) period.

	April	May	June	July	August	September	April-September Mean	April-June Mean	July-September Mean
Percent Postfire Change - Yellowstone River									
Tons	253	154	13	-1	107	11	69	74	16
Tons/Acre-Feet	156	105	42	-1	100	20	79	80	26
Percent Postfire Change - Lamar River									
Tons		60	-8	319	1476	179	34	23	743
Tons/Acre-Feet		12	-11	114	1183	279	68	2	627

other hand, was most influenced by postfire sediment during the summer, when the postfire averages were greater than prefire: 114 percent greater for July, 1,183 percent greater for August, and 279 percent greater for September. This occurred despite the postfire reduction in precipitation. In contrast, the Lamar snowmelt postfire averages for May and June were close to or less than prefire values (+12 percent for May, -11 percent for June). The reasons for this seasonal difference are unclear, but may be related to the cooler postfire snowmelt periods and higher elevation of the Lamar River basin.

Although expressing sediment as load-per- unit- runoff permits comparison of sediment loads between periods with different streamflows and examination of loads on a month-by-month basis, this method may include some sediment that was climate-controlled rather than fire-related, because similar amounts of streamflow may be caused by different combinations of precipitation events. For example, because of a greater snowmelt runoff, a prefire July with few rainstorms could have a similar streamflow to a postfire July that had a lower snowmelt runoff and many rainstorms. In that case, the increase in July sediment after 1988 would be storm-caused (or climate-caused) rather than fire-related.

A second method to identify fire-related changes in sediment was suggested by hydrologist Phil Farnes. Instead of grouping the data by month, sediment and streamflow data was divided into two seasons: snowmelt, April-June (May-June for the Lamar River) and summer, July-September. These seasons were, in turn, divided into rising-discharge and falling-discharge days. A rising-discharge day has the same or higher mean daily discharge than the previous day (possibly caused by a snowmelt surge or a rainstorm); a falling-discharge day has a lower mean discharge than the previous day. This method enabled us to analyze snowmelt surge or summer storm days separately from other days and thus be able to better compare prefire and postfire storm periods.

To identify fire-related increases in sediment not caused by climate changes, we determined regression equations that describe the relationship between streamflow and sediment for the prefire period and used them to calculate the predicted sediment loads for the postfire period. If an actual postfire load was greater than the predicted load for a given season, then the increase could be related to the fire events. For example, we first determined equations that related suspended sediment to streamflow for all the rising-discharge days during the prefire (1985-1987) snowmelt periods. Using the measured streamflow for each postfire (1989-1992) snowmelt rising-discharge day in the prefire equation, we calculated the predicted sediment load for each day and then summed these daily values to obtain a predicted load for all the postfire snowmelt period rising-discharge days. This would be the total sediment load that the Yellowstone or Lamar rivers would be expected to carry during snowmelt (rising-discharge days) if the fires had not occurred. We then compared this predicted load to the load actually measured for all the postfire snowmelt rising-discharge days. If the measured load was greater than the predicted load, a fire-related increase was suggested. This procedure was followed for the other three datasets: snowmelt falling-discharge days, summer rising-discharge days, and summer falling- discharge days.

Although this "predicted-versus-measured load" method indicated a pattern of fire-related changes similar to that shown by the monthly load-per-unit-runoff method, the magnitude of changes in sediment was different. The Yellowstone River again appeared to have major fire-related increases in suspended sediment in the snowmelt season, when snowmelt rising- and falling-discharge day sediment increased about 60 percent. Summer increases were 30 percent for rising-discharge days and 7 percent for falling-discharge days. The Lamar River, on the other hand, appeared to have its largest fire-related increases in the summer: 473 percent for rising-discharge days and 390 percent for falling-discharge days. No fire-related snowmelt increases in suspended sediment were evident on the Lamar River using this method (Fig. 2).

Climate and Variation in Fire Effects

Our research indicated that fire-related increases in suspended sediment occurred on the Yellowstone and Lamar rivers following the 1988 wildfires, but not in all seasons, and that the hydrologic behavior of burned watersheds can vary greatly. Postfire increases in suspended sediment were most evident on the Yellowstone at Corwin Springs during spring snowmelt, while the Lamar did not transport abnormally large sediment loads. On the other hand, summer suspended-sediment loads increased dramatically in the Lamar, but were not measured downstream on the Yellowstone at Corwin Springs. Evidently the runoff from unburned watersheds or those not receiving summer storms were enough to dilute the sediment effects from the Lamar River.

The bulk of suspended sediment in this region is transported in rivers during the spring snowmelt season; even large increases in summer sediment load are small by comparison to snowmelt loads. Thus, despite large postfire increases in summer sediment loads for the Lamar River, its mean postfire load (18,253 tons) was less than 10 percent of the mean total load (193,669 tons).

Postfire climate played an important role in influencing the sediment response of the Yellowstone and Lamar rivers. The first two years following the fires had relatively cool springs and few prolonged warm intervals, resulting in modest snowmelt runoffs. Watersheds are most vulnerable to accelerated erosion in the years immediately after wildfires, when burned surface vegetation has not had time to regenerate. If there had been high snowmelt runoffs in the springs immediately following the fires, sediment transport could have been much higher. The cooler postfire snowmelts from 1989 to 1992 may have also mitigated the snowmelt sediment response of the higher elevation Lamar basin, which was burned over a greater area than many of the other watersheds in the Yellowstone drainage from Yellowstone Lake to Corwin Springs. We would naturally expect that it would also show the greatest suspended-load response to the fires.

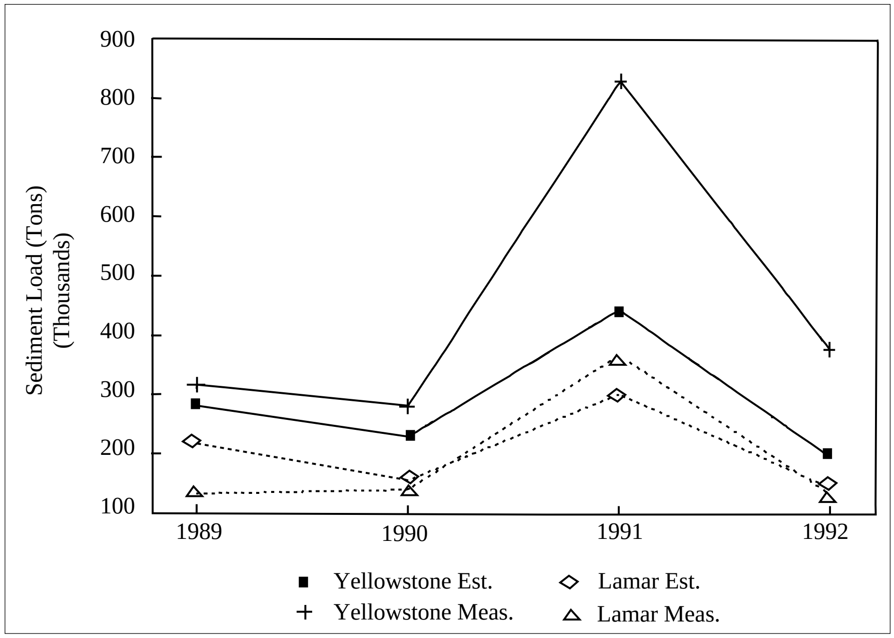

Figure 2. Estimated and measured suspended sediment loads for the Yellowstone River (April-September) and the Lamar River (May-September) for postfire years 1989-1992.

Again, this study attempted to measure the effects of the fires only upon suspended sediment, not total fluvial sediment, in two of Yellowstone's major rivers. The portion of total sediment load carried as bed load (coarser sediment) is often larger as one approaches the mountainous headwaters of rivers. The behavior of coarser sediment in mountainous watersheds following fires may be different from the suspended or finer sediment portion of the total sediment load in magnitude or timing of its response. Indeed, there is evidence to suggest that there were substantial coarse sediment and mass movement responses to the Yellowstone fires. Studies of burned and unburned watersheds in the Shoshone National Forest indicate that there were major events of coarse sediment transport in the first years after the fires without a corresponding increase in suspended sediment. Forest staff conducted field trips of fire-affected watersheds scoured and incised by high-volume coarse sediment flow during summer storms. Field trips in the Lamar River basin found numerous instances of burnt-out woody debris jams which would release impounded coarse bed-load sediment upon the first high-streamflow storm. Likewise, Grant Meyer documented the effects of fluvial, hyper-concentrated, and debris flow events in the Lamar watershed in 1989 and 1990 in his study of fire and alluvial change. These observations indicate major changes in the amounts of coarse sediment transported and in sediment-delivery patterns in the steep mountain stream channels following the fires and provide a complementary, if qualitative, picture of fire-effects on sediment transport.

Management Implications

Findings of the postfire sediment study useful to resource managers fall into two areas: direct information and analytical tools. Establishing the normal ranges of suspended-sediment transport out of Yellowstone is direct information that can be used to compare to future sediment loads associated with specific management practices. Our sampling for sediment and streamflow before and after the fires provides baseline information on such streams as Soda Butte Creek, which could have been affected by recent developments outside the park.

This study indicates that managers can

expect climate to exert the primary influence upon the amounts of suspended sediment sent into and carried out by streams after wildfires. The spring snowmelt runoff carries most of the year's suspended sediment in streams, and the character of postfire snowmelts are critical to sediment responses. The scenario for least-transported sediment is one where the spring is cool with few prolonged warm periods, an average or low winter snowpack, and little spring precipitation. The scenario for a large post-disturbance sediment response has a warmer spring, with at least one period of several consecutive days of warm temperatures, an average to large winter snowpack, and a lot of spring precipitation.

Summer suspended-sediment transport in the badly burned steep mountain drainages of the Lamar River basin increased dramatically after the fires and yet the effects downstream were evidently mitigated by runoff from unburned watersheds or those unaffected by storms. Changes in coarse sediment delivery may have been as great or greater as these watersheds released sediment stored behind burned woody debris dams and experienced mass movement, debris, and high fluvial streamflows immediately following the fires. The mountain watersheds have been readjusting coarse sediment delivery ever since the 1988 fires and are storing released sediment behind new woody debris jams. Comparison of predicted to measured suspended sediment in the Lamar River in 1992 suggests a return to prefire levels and may indicate that readjustment of sediment delivery patterns has been accomplished.

Both linear and non-linear regression equations relating suspended sediment to streamflow for prefire and postfire periods are among the useful analytical tools we developed. If direct suspended-sediment sampling is conducted in the future, these equations can be used to compare predicted loads to measured loads. Estimations can be made as to whether the Yellowstone River drainage has returned to prefire levels of sediment transport or whether the river is becoming muddier due to wildlife grazing or other factors. For the spring snowmelt season, streamflow-sediment rating equations can be used to estimate sediment transport levels on the Yellowstone and Lamar Rivers without further sampling. Based on values of mean daily streamflow, values of suspended sediment can be assigned to each day using the proper prefire rising- or falling-discharge rating equation.

A less expensive tool to monitor sediment transport levels on the rivers can be developed from suspended sediment-turbidity data we collected. Turbidity can be measured more easily and cheaply than suspended sediment and estimates of contained suspended sediment can be made using our sediment-turbidity data and equations. These would be particularly useful during summer, when streamflow-sediment rating equations are not as accurate as those for turbidity-suspended sediment.

Relationships between precipitation at park weather stations and runoff at the Corwin Springs gaging station were revised after the wildfires. These multiple regression equations describe the precipitation-runoff relationship and were used with historical flood data to produce equations that can predict the date of peak snowmelt runoff on the Yellowstone River for a given season. This information can be of value in planning for closing areas due to high water, predicting earliest dates for fording rivers, or other activities that require knowledge of the date of peak river flow. Finally, information on suspended sediment levels and hydrological patterns can be useful to fisheries and aquatic ecology studies.

The Importance of Baseline Data

As the United States becomes more developed, we need to measure the physical and ecological processes in wildland areas so that we can judge possible effects of natural or anthropogenic disturbances. If we do not know the hydrologic and sediment behavior in unmanipulated landscapes, we cannot know how far watersheds will deviate from normal when modified by construction, agriculture, or natural disturbances such as fires. Put another way, how can we judge if a stream is acting "naturally" without comparing it to streams in wild, unmodified landscapes? Few undammed or undiverted watersheds such as the Yellowstone River are left to study in the United States. It was fortuitous that three years of sampling and measurement had been completed before the 1988 fires, for without it, we could not have measured the effects of the fires upon suspended sediment loads. Resource managers now have a suspended sediment database that can be used as a yardstick in the future. For instance, comparison of 1992 data to the prefire average indicated that the Yellowstone River had not yet returned to prefire levels of sediment transport. How long did the effects of the 1988 fires last? Are the effects, in fact, over? Is the Yellowstone River getting muddier due to wildlife overgrazing, as anglers suspected in the days of the sediment study? Is uplift of parts of the Yellowstone plateau by underlying magma causing increasing sediment transport? These questions cannot be addressed, much less answered, without a historic database of natural resource information.

In retrospect, driving many miles each week, hiking up burned-out mountain streams, sampling in the rain and snow, and hanging out over rivers late at night, proved to be only slightly crazy and well worth the effort.

Roy Ewing studied northern Yellowstone's watersheds from 1985 to 1994, seeking to shed some clarity on the murky issue of muddy waters. He has a master's degree in geology from the University of Tennessee. While with the Peace Corps in India he worked on a water drilling project. He currently lives in his home state of Tennessee.

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