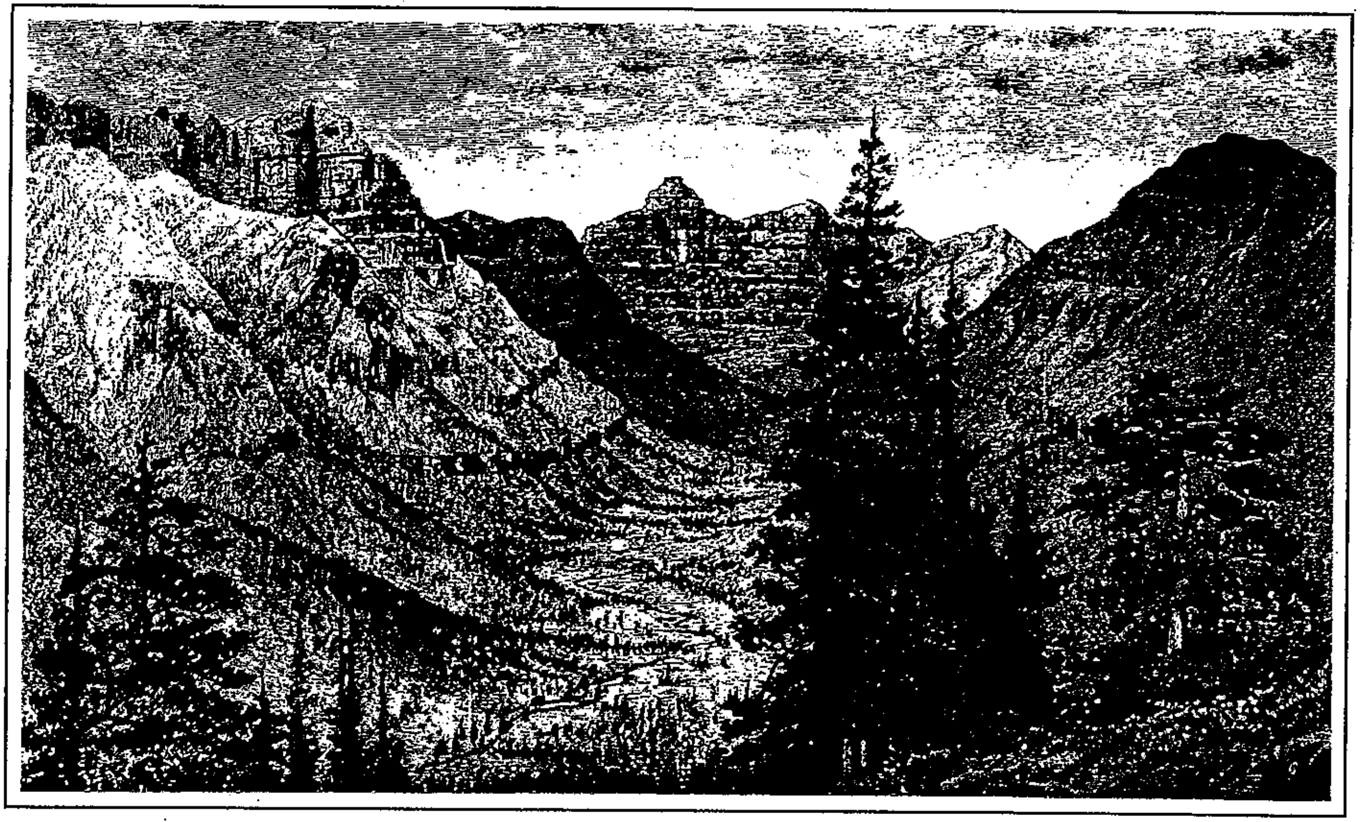
Yellowstone Science

A quarterly publication devoted to the natural and cultural sciences



Soda Butte Creek Pollution

The View from Tasmania

1988: Five Years After

Large Lakes and Fire

Volume 2 Number 1

Change

The old saying that "the only thing worse than change is sudden change" is perhaps never more true than when applied to an institution. Bureaucracies exist, as Yellowstone Superintendent Bob Barbee has put it, "to police the status quo," not to go adventuring in their own evolution. The science bureaucracy of Yellowstone, however, has experienced a double whammy of change in the past year.

More than a year ago, the park staff started deliberations that resulted in the new and very promising Yellowstone Center for Resources. The potential benefits for the park's resources, and for science, still seem significant, if not extraordinary. In fact, those benefits are now appearing, as a finer system for taking care of pressing resource issues emerges. But changing a bureaucracy is enormously disruptive of whatever that bureaucracy happens to have going at the time. As one observer put it a few months ago, "if we were wearing mood rings, they'd all be black."

Then, early in 1993, the Secretary of the Interior included himself in this process by announcing a massive reorganization of science throughout the Department of the Interior, to create a whole new agency, the National Biological Survey. The NBS, like the Center, sounds like a good idea to a lot of people, and not such a good idea to others, but in any case it's pretty sudden. As the new fiscal year begins and the new agency materializes, many Yellowstone personnel, and thousands of other federal employees, might conservatively be described as curious about how it's all going to work out.

In this charged and nebulous atmosphere, *Yellowstone Science* offers the modest consolation of Stuff That Can Be Quantified. It provides some interesting lessons in the nature of change too, whether sudden or gradual. Grant Meyer reveals yet another impressive (if dismaying) way in which the Yellowstone landscape has recorded its own past for our consideration. Richard Lathrop concludes that Yellowstone's large lakes have an admirable durability in the face of widespread watershed disturbance. A Tasmanian ecologist reminds us that whatever Yellowstone is up against, it's no worse (and maybe better) than what the rest of the world faces. And Dennis Knight summarizes dozens of recent fire-related studies, offering hope and enthusiasm for all we have yet to learn.

So whatever your position, if any, in all the current turmoil (lately, my own bewilderment has focused on just how long sudden change can drag on), take heart that Yellowstone will still be there, exercising its amazing dual capacity for resilience and change, when we again turn all of our attention to it.

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Paul Schullery
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Bozeman, Montana

On the cover: "Valley of Soda Butte Creek, showing stratified conglomerates," an illustration in F.V. Hayden's U.S. Geological and Geographical Survey of the Territories, Part II *(1878). See Grant Meyer's article about Soda Butte Creek and its pollution history, beginning on page 2.*

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A new twist in the saga of Soda Butte Creek

Renee Evanoff

A Polluted Flash Flood and Its Consequences

by Grant Meyer

Soda Butte Creek, flowing through the spectacular scenery of northeastern Yellowstone National Park, is a rarity among the park's streams—it is polluted. Once as productive and admired by fishermen and naturalists as many other park streams, the creek was considered a lost fishery by the mid-1900s, and has only slowly and partly recovered since then.

The creek has been under scientific scrutiny in recent decades because of pollution sources on its headwaters outside of the park. The tailings impoundment associated with the McLaren mine was located on Soda Butte Creek near its junction with Miller Creek, just east of Cooke City, Montana, four miles upstream from the park boundary. The mine, active from 1933 to 1953, was primarily a gold mine, but also took silver and copper; it was said to be the largest gold mine in Montana at the time. Both cyanide and arsenic were used in the extraction of gold from the ore.

The mine tailings have long been identified as a source of pollution in Soda Butte Creek, and numerous studies have been undertaken to determine the effects on the creek's ecology. The Soda Butte Creek situation is often seen as an instructive example of the complexities of managing a wild river across administrative boundaries when the mandates of the managing agencies conflict, but it is also instructive as a case study of how pollution works, how many ways its effects must be measured, and how long such abuses may outlast the activity that caused them.

While working on his Ph.D. research project (University of New Mexico), on the subject of sedimentation caused by forest fires, Grant Meyer conducted a study of how the Soda Butte "alluvial system" has been affected by major fires and climatic changes over postglacial time. Incidental to that study, he discovered that some of the McLaren tailings had been washed down the floodplain of the creek, greatly complicating the nature of future pollution and adding a new dimension to our understanding of the Soda Butte Creek problem.

Grant's Ph.D. research was funded

by the National Science Foundation; the funding of the research for the technical report upon which this article is based was provided by the National Park Service. Ed.

Part of my work involved mapping of former floodplain surfaces, or terraces, along Soda Butte Creek, as well as delineating the present floodplain. During these investigations, I noticed an unusual layer of strongly oxidized, bright orange-red overbank sediments at many localities along the present floodplain; their rusty appearance contrasted strongly with the tan-brown color of more typical overbank deposits. Overbank sediments are deposited by the slower-moving water which spreads out over the floodplain when a stream rises over its banks during a flood, and are generally composed of layered sand, silt, and clay.

The oxidized sediment layer lies at or very near the top of overbank deposits of the present floodplain, suggesting that they appeared there quite recently. Ages of trees on the present floodplain and on the lowest terrace above it (determined from increment boring of the trees to count rings) suggest that Soda Butte Creek has occupied the present floodplain level for about 150 years.

The present floodplain is not flat and featureless; in many places, it consists of two or three distinct levels of flood-deposited bars. The oxidized sediments are generally found above the lowest, most frequently flooded surfaces, but below the highest flood bars. The ages of trees on these highest flood bars suggest that the bars were formed by several large floods between about 1880 and 1920. A Yellowstone Park Superintendent's Report documents a flood in June of 1918, which washed out the Lamar River Bridge, downstream of the Soda Butte confluence. With this background, I suspected that the orange-red deposits were deposited within the last 70 years.

Tracking the Sediments

I mapped the oxidized overbank sediments at a number of locations, extending from just below Cooke City, Montana, downstream more than 15 miles to the broad floodplain just upstream from the Soda Butte Creek footbridge and gaging station. This mapping, however, included only readily visible deposits; it is safe to assume that the oxidized sediments are more widely distributed throughout this reach, and probably extend below this reach as well.

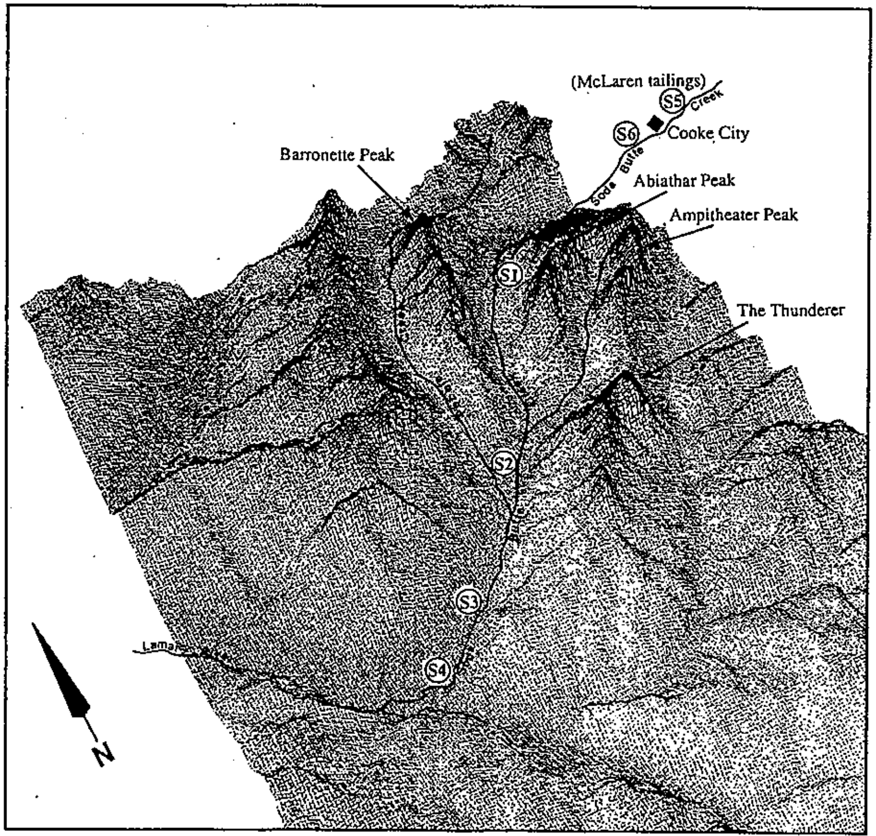
The sediments occur as a discrete stratigraphic layer of thinly-bedded fine sand, silt, and clay. The layer is sharply bounded (that is, its edges are quite clear on top and bottom) and readily discernible where it rests on the distinctly different unoxidized overbank sediments. The thickness of the oxidized layer ranges from 14 inches (35 cm) and more in localities near Cooke City, to 2 inches (5 cm) or less near the Soda Butte footbridge. The thickness of the layer generally decreases downstream, but thicker accumulations occur in slackwater areas on the floodplain.

Grant Meyer

In some places, the polluted sediments are exposed (light unvegetated area in foreground) on the soil surface.

The consistently strong oxidation and the sharp boundaries of the oxidized sediment layer suggested to me that the sediments were oxidized prior to arriving in their present location, and were deposited during a single flood event. I hypothesized that the orange-red deposits were created by a flood that had carried material from the similar-appearing McLaren mine tailings just upstream from Cooke City.

To test my hypothesis, I collected samples from the oxidized floodplain sediments at five locations along Soda Butte Creek (see map), and from the McLaren tailings pile.



Branch of Resource Technology, Yellowstone Center for Resources/Renee Evanoff

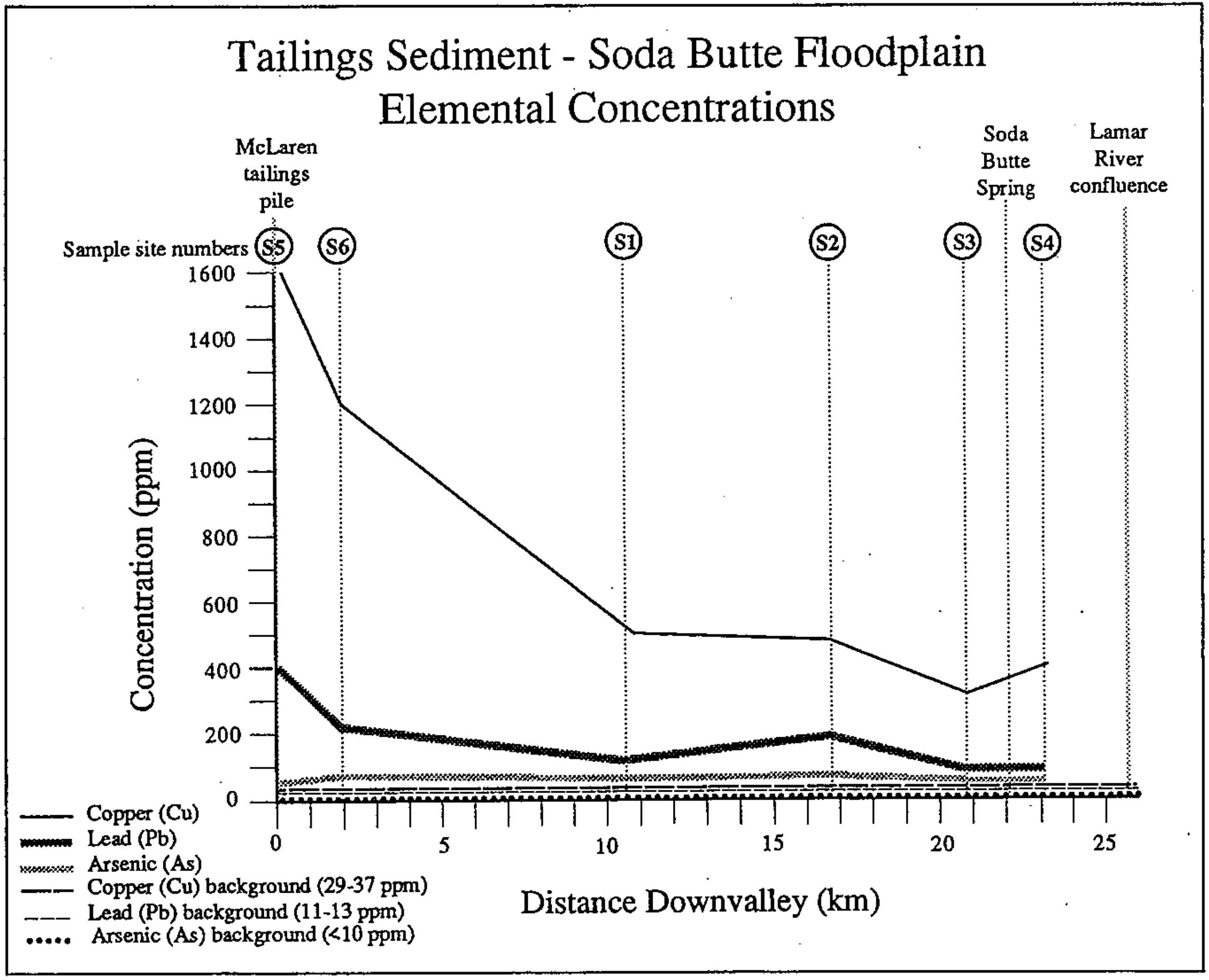


Table showing the relative abundance of three key contaminants. Sample site locations are shown on the map on page 3. "Background" levels of the three elements refer to naturally occurring levels in soils near the floodplain.

For geochemical comparison with other sediments from the same area, I took two "background samples" from unoxidized overbank sediments on other Soda Butte Creek terraces. These sediments were deposited hundreds to thousands of years before modern times and therefore are regarded as non-polluted.

I also sampled from two locations in unoxidized overbank sediments that were deposited by small floods within the last several years. Although not visibly oxidized, these sediments post-date the time of dumping of the McLaren tailings, and thus may contain small quantities of tailings material. All of these samples were analyzed for selected major, minor, and trace element composition by D.L. Fey, Branch of Geochemistry, U.S. Geological Survey, Lakewood, Colorado.

Verifying the Source

The results of the sediment and tailings chemical analyses strongly supported my hypothesis of a McLaren tailings origin for the oxidized floodplain sediments. According to past analyses and my own, the McLaren tailings have high levels of iron (11.7 to 26.1 percent), copper (841 to 12,600 parts per million, hereafter abbreviated as ppm), lead (71 to 672 ppm) and arsenic (35 to 97 ppm). The concentration of iron is two to five times higher in the tailings, and two to three times higher in the oxidized floodplain sediments, than in the background floodplain sediment samples.

Similarly, concentrations of copper and lead are higher by one to three orders of magnitude (that is, 10 to 1,000 times higher) in the tailings than in the background samples I collected. These elements are also 4 to 20 times more abundant in the oxidized floodplain sediments than in the background samples.

Copper leaching directly from the McLaren tailings pile has been previously identified as a serious detriment to water quality in Soda Butte Creek. Copper is particularly elevated in the oxidized floodplain samples (310 to 1200 ppm, well in excess of the typical range of 1 to 150 ppm in uncontaminated surface soils of the United States).

Zinc in the tailings is about one and a half to two times greater than in the background samples, and all of the oxidized sediment samples except those collected at site S1 show slightly elevated zinc levels.

Interestingly, each of the above metals was also more abundant in the two post-tailings background samples than in the pre-tailings background samples. Copper and lead values were twice as large in the post-tailings background samples (although still well within the typical range for uncontaminated soils in the United States). These results suggest that low-level pollution of fine sediment continues to occur in Soda Butte Creek through reworking of materials previously released from the tailings pile.

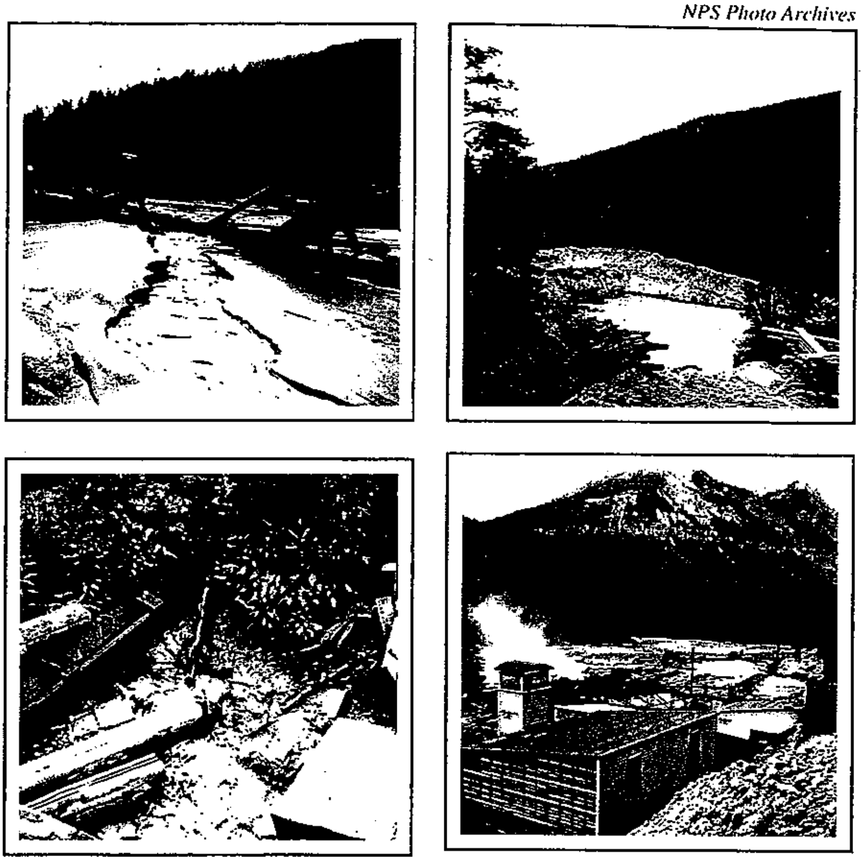
Arsenic was measured at 47 ppm in the tailings and was found in generally similar concentrations in the oxidized sediment. However, arsenic in each of the background samples was less than the detection limit of 10 ppm, again suggesting that the source of arsenic in the oxidized sediments is the McLaren tailings. As might be expected given their appearance, both the tailings and the oxidized sediment were high in iron (21 percent and 8.3 to 16 percent, respectively), whereas the background samples all contained about 5 percent iron.

Copper, lead, and iron each declined in concentration fairly consistently downstream from the McLaren tailings pile as might be expected given dilution of the tailings sediment with uncontaminated sediments during downstream transport.

On the other hand, some elements in the oxidized sediments, including calcium, manganese, barium, strontium, and nickel, tended to increase in concentration downstream. These elements are found in much lower concentrations in the McLaren tailings than in the background samples, thus the effect of tailings pollution is to reduce their concentrations. After deposition, the acidic tailings may also promote removal of more mobile elements such as calcium from the polluted overbank sediments.

This may explain why, in a floodplain area about 1.9 miles (3 km) downstream from Cooke City, I observed an accumulation of calcium carbonate in unoxidized sediments a few centimeters below a thick deposit of the oxidized sediments. Calcium dissolved within the acidic tailings-polluted sediment was apparently moved downward by percolating water and reprecipitated in the sediments below.

NPS Photo Archives



The McLaren Mine tailings site, just east of Cooke City, Montana, as it appeared a few years prior to the flash flood that released tailings materials into the Soda Butte Creek drainage.

Causes and Consequences

The McLaren tailings pile is the only reasonable source for the metals-laden oxidized sediments on the Soda Butte Creek floodplain. The flood event depositing these sediments must have occurred during or after dumping of the tailings between 1933 and 1953.

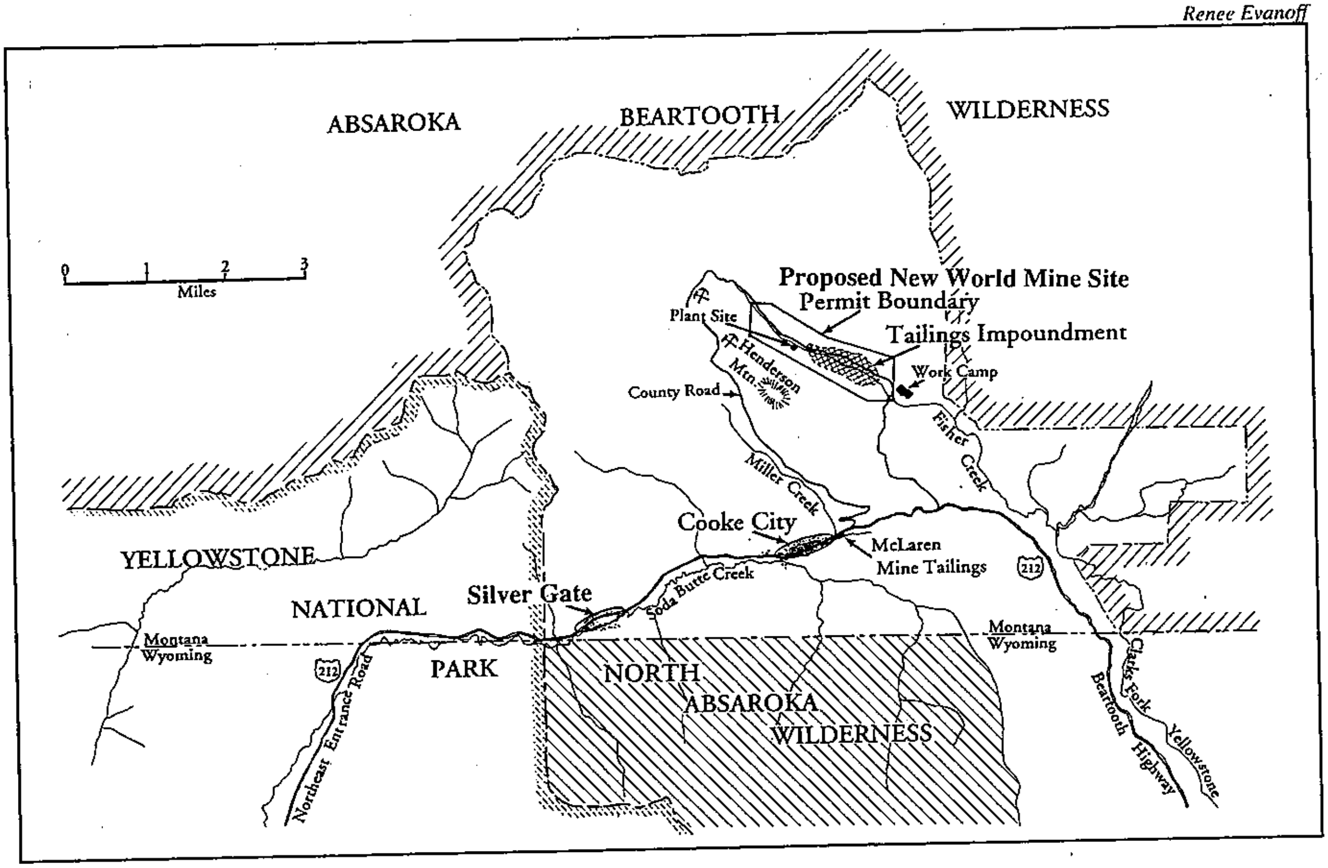
Long-time Cooke City residents (interviewed by local historian Ralph Glidden in 1992) recalled a failure of the McLaren tailings impoundment dam during the summer of 1950 or 1951. They believed that the dam break occurred due to a series of heavy rainstorms and flash floods in the upper Soda Butte basin. Possibly, failure of a small tailings pond on Miller Creek also added to the flood flow that breached the dam.

Indeed, a search of National Park Service records uncovered mention of a major dam break and tailings spill from the McLaren impoundment in June 1950. Although no specific date for the dam break is given, the report states that the break was being repaired on June 28, 1950. Given the time of year, it is likely that snowmelt runoff also contributed to the flood event.

Although studies of the water quality degradation caused by leaching of metals from the main tailings pile have been conducted, the specific environmental effects of the tailings sediments on downstream floodplain areas need more investigation. Concentrations of copper in the tailings sediments substantially exceed the 100 to 125 ppm level considered to be toxic to plants, and lead is near the toxic threshold of 100 to 400 ppm.

Informal observation suggests that vegetation has not responded consistently to the oxidized sediments. Some of the drier sites where the oxidized sediment is at the surface are very sparsely vegetated with grass or unvegetated, whereas nearby sites on unoxidized sediment have greater grass cover. However, other sites on the oxidized sediment are heavily vegetated with grass, forbs, willows, and conifers

Renee Evanoff



The area just northeast of Yellowstone Park, including the headwaters of Soda Butte Creek and the site of the McLaren tailings, are currently the focus of debate surrounding a new mine, whose proposed site and tailing impoundment are shown above, north of Cooke City, Montana.

(including site S6, with 1,200 ppm copper).

Copper is highly toxic to aquatic life; indeed, copper sulfate has long been used to kill off unwanted plants and fishes in ponds. However, the amount of copper that may be entering Soda Butte Creek through the floodplain tailings deposits is unknown. Nevertheless, there is cause for concern, because 1) concentrations of copper in the oxidized sediments are quite elevated, and in the upper drainage, are nearly as high as in the tailings themselves; 2) there are indications of acidic conditions and strong leaching in the oxidized sediments; and 3) shallow groundwater flows through many of the tailings-contaminated areas before discharging into Soda Butte Creek.

Also, subsequent floods will pick up the tailings-contaminated sediments from the floodplain, possibly causing toxic concentrations of metals in Soda Butte Creek.

The threat to the ecological health of Soda Butte Creek through leaching of the intact mine tailings above Cooke City has been well known for many years. This study suggests that a second source of pollution, in the form of contaminated sediments spread down the drainage, may pose an additional threat. Contamination from eroded tailings exists within many streams in historic mining areas of the western United States; the upper Clarks Fork of the Columbia River below Butte, Montana, is an example of severe and continuing problems stemming from tailings sediment pollution. Once this fine toxic sediment is distributed broadly over floodplain areas, it becomes very difficult and expensive to remove or treat.

Though considerable reclamation work has been completed at the McLaren tailings site, the main tailings pile is still not completely safeguarded against flood erosion. To mine developers, valley floors present attractive and economical sites for tailings disposal; however, these sites are inherently subject to the ravages of infrequent but inevitable major flood events, particularly in a dynamic mountain environment such as the Cooke City area.

Typically, tailings remain hazardous long after mine operation ceases, at least for hundreds of years. Even where drainage systems have been properly engineered to prevent erosion, continued maintenance is required. Present mining laws do not provide for mitigation of such long-term problems. The Soda Butte Creek example underscores the need for careful consideration of the impacts of mine development, especially where other, higher values of the land and its resources may be at stake.

The report from which this article was derived, "Mine tailings sediment contamination in the Soda Butte Creek drainage, Montana and Wyoming," by Grant Meyer, is now in preparation for publication. Grant's research on fire and climate history in northeastern Yellowstone National Park is more completely described in his 1993 Ph.D. dissertation, "Holocene and Modern Geomorphic Response to Forest Fires and Climate Change in Yellowstone National Park" (University of New Mexico).

The 1988 Fires and Yellowstone's Large Lakes

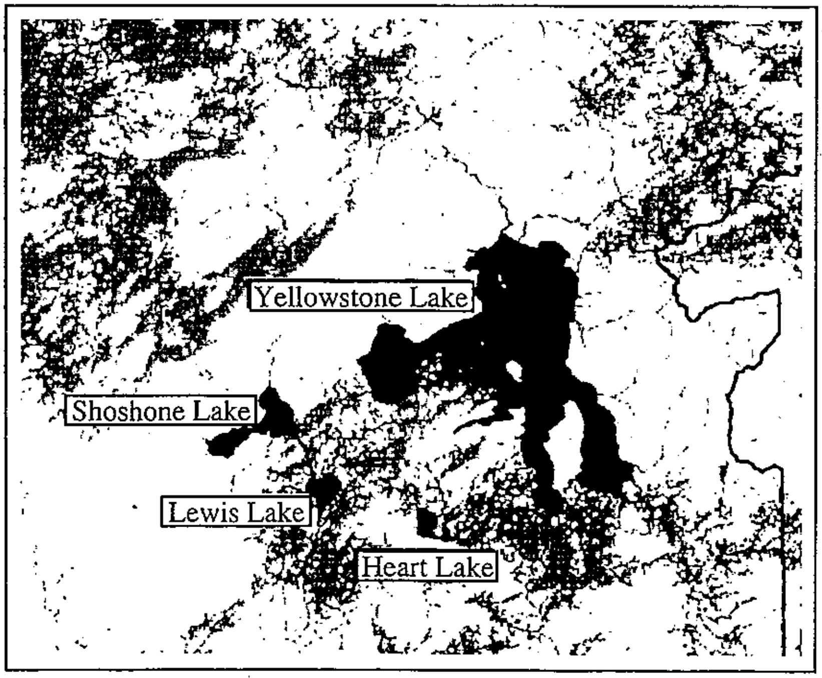
Monitoring the impacts of landscape-scale fires

by Richard G. Lathrop Jr.

The fires that burned the greater Yellowstone area (GYA) during the summer of 1988 were the largest ever recorded for that area. The intensity and scope of the 1988 fires prompted great concern over the impacts on the area's natural ecosystems and wildlife. In addition to its obvious direct effects on forest ecosystems, fire can have profound indirect effects on aquatic ecosystems.

Fire may free nutrients (for example, nitrogen, phosphorus and cations: calcium, magnesium, potassium, and sodium) otherwise immobilized in biomass or soils, and increases the release of ions and nutrients from the uplands to downstream aquatic ecosystems. Until postfire vegetation is sufficiently established, the reduction in canopy cover can result in increased sediment erosion and runoff. As postfire monitoring in the GYA by the National Park Service, USDA. Forest Service and others has demonstrated, a number of stream and river systems have experienced dramatic pulses of sediment and nutrients during the spring freshet period or following summer thunderstorm events. The Yellowstone River ran black as ink several times during the summer of 1989.

Lakes, in their role as a hydrological collection basin, act to integrate (but also dilute) the inputs from upland watersheds. Thus, fire impacts on lakes might be expected to be more subtle but also longer-term, as compared to stream systems. Stemming from my interest in the linkages between terrestrial and lake/coastal systems, I wanted to investigate the impacts of the 1988 fires on the water quality of the area's large lakes. The extreme severity of the summer of 1988 fire season presented a unique natural experiment: an opportunity to examine land-water linkages for sev-



The watersheds of Yellowstone's four largest lakes were burned (shaded areas) to varying degrees in 1988. Map by the Branch of Resource Technology.

eral coupled watershed-lake basins.

Three of Yellowstone's four large lakes (Yellowstone, Shoshone, Lewis, and Heart, in order of size) had significant portions of their drainages burned during the 1988 fires. Twenty five percent of the Yellowstone Lake watershed, 26 percent of the Lewis Lake, and 52 percent of Heart Lake watersheds were affected by the fires to some degree (based on information derived from the Yellowstone National Park geographic information system). Jackson Lake in Grand Teton National Park had 26 percent of its watershed burned.

The basic question I was interested in was whether there was a significant change in lake water quality subsequent to the 1988 fires. To adequately answer this question, I needed to compare water quality data from before and after the event. Finding such data is often difficult, especially in remote areas such as the GYA. Luckily the U.S. Fish and Wildlife Service (USFWS) and the National Park Service have been conducting a water quality monitoring program for Yellowstone's four major lakes since the mid to late 1970s. This monitoring program halted in 1985 due to a shortage of funds, but resumed in 1989 with systematic sampling of Yellowstone and Lewis Lakes (funding as well as accessibility constraints have precluded a regular sampling program on Shoshone and Heart Lakes).

Unfortunately, there is no similar monitoring program on Jackson Lake. Monitoring is a thankless job but the forethought and perseverance of the USFWS, in particular Ron Jones, Bob Gresswell, and Dan Carty, and their willingness to share the data is greatly appreciated.

Water quality, a somewhat ambiguous term, is generally defined as the chemical, physical, and biological condition of water related to beneficial use by humans, or more appropriately in the case of Yellowstone National Park, by wildlife. The USFWS lake water quality monitoring program has consisted of a series of measurements.

A "temperature profile" is compiled that gives the water temperature at various depths. Water transparency is measured with a "Secchi disk," a metal or plastic disk painted black and white, whose visibility at various depths indicates how much suspended or dissolved (but colored) material is in the water column. Several simple water chemistry parameters are measured directly in the field, such as conductivity, which gives an index of the dissolved mineral concentration and pH, which is a measure of acidity. Water samples are taken and sent to a commercial laboratory for analysis. More than 30 chemical parameters are measured.

Richard Lathrop Jr.

USFWS netting plankton during water quality sampling on Yellowstone Lake.

If large amounts of dissolved ions (positively or negatively charged atoms) were being leached from the burned portions of the upland watershed, then there might be a measurable increase in the ionic content of the lake's waters. Based on previous research, I selected several parameters for detailed analysis. Specific conductivity, pH, total dissolved solids (another index of dissolved mineral or ionic content), and total hardness were evaluated as general indicators of water chemical quality. In addition, specific dissolved ions found to have increased due to fire disturbance in other studies were analyzed: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chlorine (Cl) and sulfate (SO_4). The USFWS long-term monitoring program provided critical baseline data on the prefire status, which I compared using various statistical techniques to the postfire period.

Comparison of the prefire and postfire water quality data sets showed that there has been some measurable change in the water quality of Yellowstone's major lakes. Secchi disk transparency, Ca, Cl, and SO_4 have generally all decreased. Conductivity, pH, total dissolved solids, Na, and K have generally increased.

However, due to the great intra- and inter-annual variability that naturally occurs in the measured parameters, only several parameters show statistically significant differences. For example, conductivity and pH increased (as might be expected from postfire inputs) significantly so at only two of the four stations. Ca and SO_4 concentrations have significantly decreased for all of Yellowstone Lake stations. Ca has significantly decreased in Lewis Lake (but not SO_4). Based on a number of stream water quality-fire impact studies, I expected Ca and SO_4 to increase, not decrease as was found.

As with many other complex environmental systems, it is hard to definitively link cause and effect with strictly observational data. Several other environmental processes have a potential role in determining lake water quality. For example, nutrients and chemical ions are present in the atmosphere and may be deposited directly to the lake's surface in precipitation.

Analysis of the atmospheric deposition data from the National Atmospheric Deposition Program (NADP) sampling station located at Tower Falls (in Yellowstone National Park) provides an alternative explanation of some of the observed changes in water quality. The NADP data showed a decrease in concentrations of Ca, SO_4 and an increase in pH during the same time period. This mirrored the trends found in the lake water quality record.

Thus the measured changes in the water chemistry of Yellowstone's major lakes may be due to changes in atmospheric deposition rather than increased fire-related inputs from the upland watersheds. The significant but variable inputs from Yellowstone Lake's hydrothermal springs or other nearby geothermal features may also have a major impact on water quality, as suggested by Val Klump of the University of Wisconsin-Milwaukee.

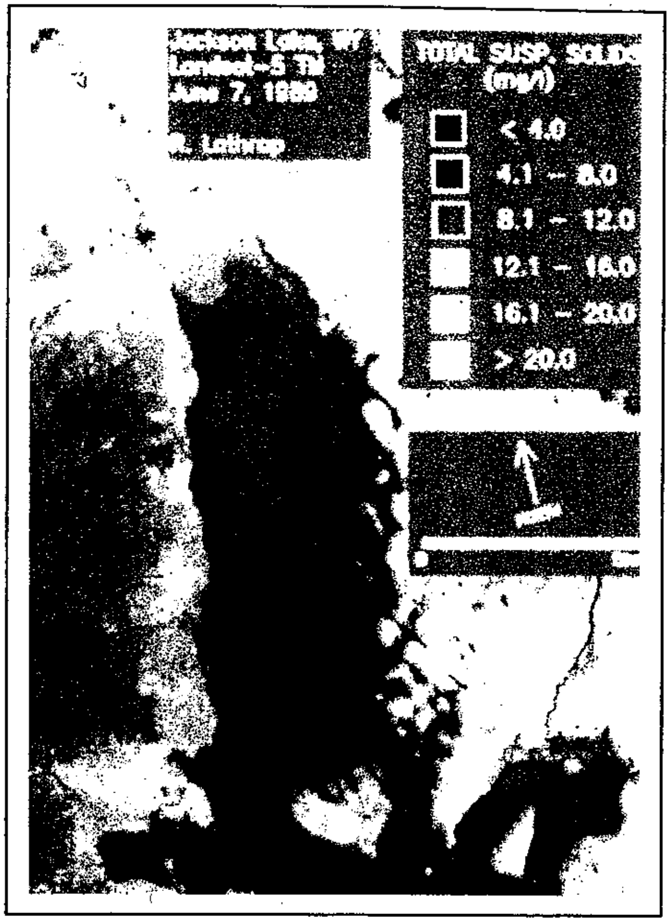
Further complicating the issue has been the change in fisheries management policy since the 1970s, which has resulted in an increase in the top predatory fish, Yellowstone cutthroat trout. Research on other large lake systems has suggested that fish populations have "cascading" impacts on lake trophic state and water quality through the "top-down" or biological control of lake productivity.

An obvious weakness in my study has been the lack of a nutrient or chemistry budget detailing the magnitudes of the inputs and outputs to the lake. Concrete data on the direct input of sediment and nutrients from the tributaries to Yellowstone's major lakes was not available. I am unable to say whether the direct input of dissolved ions from streamwater increased or not.

Other postfire studies do provide some evidence that the fires did increase the influx of sediment and nutrients to the park's aquatic ecosystems. Sampling of stream water chemistry in the Silvertip Watershed Monitoring Project in the adjacent Shoshone National Forest has shown significant increases in sediment, potassium, silica, total phosphorus, and specific conductance for a heavily burned watershed.

Other stream sampling work, conducted by James Brass and Paul Sebesta of the NASA-AMES Research Center and Philip Riggan of the USDA Forest Service-Riverside Fire Lab in northern Yellowstone shows heavy pulses of sediment and nutrients from fire-impacted watersheds. My analysis of U.S. Geological Survey (USGS) monitoring data for Flagg Ranch on the Upper Snake River (which drains the Shoshone, Lewis, and Heart Lakes' watersheds) shows large pulses of total phosphorus and total nitrogen following the 1988 fires (as compared to 1988 data, the only year of prefire data available). However, there has been little to no change in specific conductance or concentrations of ions.

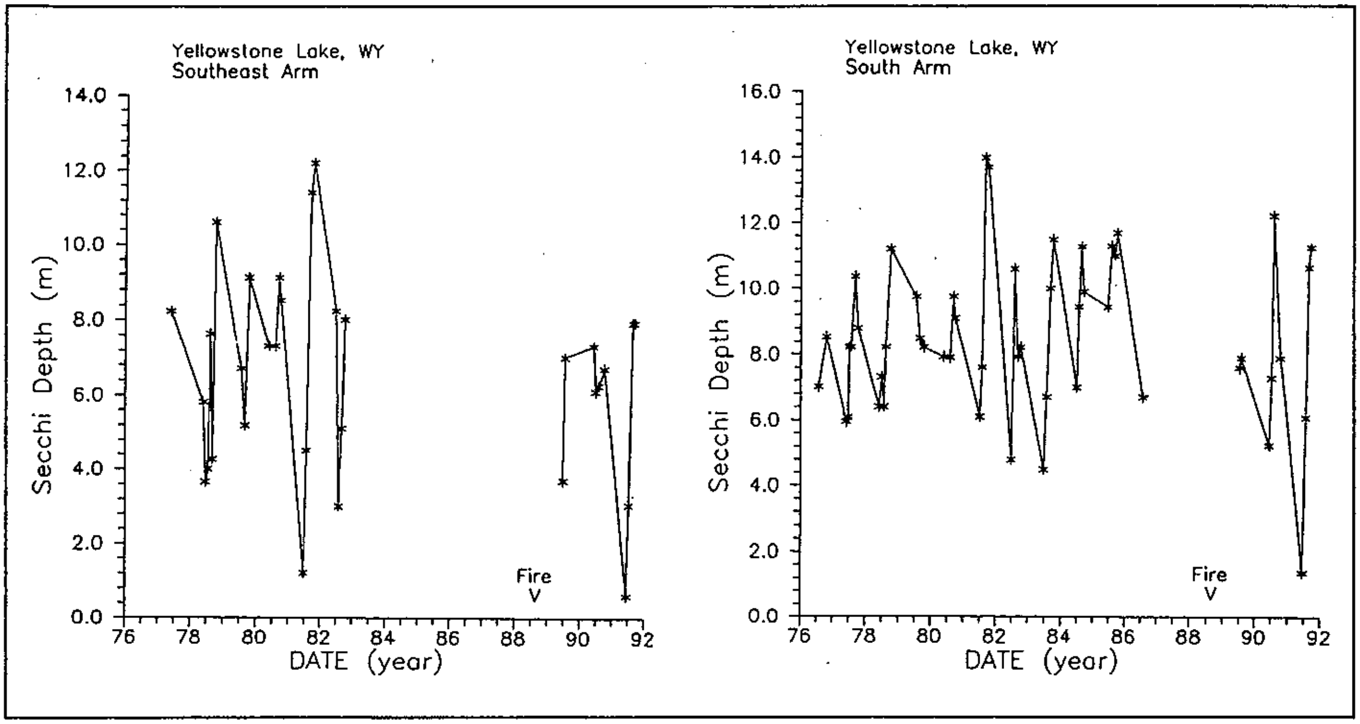
Landsat Thematic Mapper image of Jackson Lake, calibrated to display suspended sediment concentration. Note the plume of turbid Snake River water extending down the western side of Jackson Lake.



As an additional source of environmental monitoring information, I used satellite imagery to give a different perspective. My previous research, in the Great Lakes, has shown that the big-picture view provided by satellite remote sensing systems make them a useful tool in monitoring large lake systems. Specifically, I have used remote sensing scanners to measure the changes in a lake's water color due to influx and dispersal of turbid river plumes. Landsat Thematic Mapper imagery taken in June of 1989, show relatively small plumes of turbid water, in this case due to high suspended sediment loads, where Pelican Creek and the Upper Yellowstone River enter Yellowstone Lake. The water color (transparency) of the vast majority of the lake remained unaffected.

The turbidity plume in Jackson Lake caused by the Snake River is much more dramatic. During the height of the first spring runoff after the 1988 fires, the satellite imagery (June 7, 1989) shows the river plume with higher concentrations of suspended sediment (confirmed by simultaneous lake water sampling) extends two-thirds of the length of Jackson Lake. Comparison of satellite imagery from the prefire (1987 and 1988) with the postfire (1989 and 1990) period shows that the Snake River plume, a normal occurrence during the spring freshet period, was enhanced in the postfire period. This interpretation is supported by analysis of USGS monitoring data for the Snake River (from Flagg Ranch, approximately five miles, or 8km, upstream of Jackson Lake) which shows large pulses of suspended sediment following the 1988 fires (as compared to 1988 data, the only year of prefire data available).

Overall, the measured effects for Yellowstone and Lewis Lakes are quite subtle, and do not qualify as a gross or major shift in water quality. Three years of postfire data was deemed sufficient to show initial impacts on lake water quality. However, many burned areas have not fully revegetated and nutrient export from the uplands is likely still occurring. Longer-term effects are still possible. Due to the large volume of Yellowstone Lake and its long water renewal time (the time it takes for the entire lake to be replaced by new water, in this case approximately 10 years), the maximum effect may lag behind maxi-



The graphs above show water transparency for two monitoring stations on Yellowstone Lake. Water quality is measured using a Secchi Disk, as described in the text on page 8. Notice that the depth at which the disk remains visible varies considerably, both in a given year and from year to year (greater depth of visibility means higher transparency of the water). This is typical of natural lake dynamics. Note also that the prefire and postfire measurements greatly overlap in range.

mum yield from the stream inputs by several years.

In addition, there may be more subtle effects that have not been detected by either the sensitivity of the existing lake water quality monitoring program or the statistical techniques used in this analysis. The postfire sampling program was restricted to using the same monitoring strategy, both parameters measured and techniques used, to be consistent with the prefire sampling program. Analysis of preserved phytoplankton samples (part of the USFWS monitoring program) to examine changes in the assemblages of phytoplankton species might show more subtle impacts of the fire on the lake's biota; work along this line is being undertaken by Edward Theriot of the Philadelphia Academy of Natural Sciences.

Jackson Lake appears to be receiving a higher input of suspended sediment but the consequences on the lake system are unknown because of the lack of systematic prefire and postfire monitoring data. Compared to Yellowstone Lake, Jackson Lake has a much larger watershed area in comparison to its volume; therefore it has less capability to dilute increased inputs from the land surface. With its shorter water renewal time (approximately three years), Jackson Lake should respond more quickly to events such as fire disturbance in its watershed. Conversely, a shorter water renewal rate also means that any increased inputs are flushed from the lake at a faster rate.

In 1982, William Romme of Fort Lewis College and Dennis Knight of the University of Wyoming first hypothesized that Yellowstone Lake productivity is to some extent synchronized with the long-term fire cycle (on the order of 200-300 years) that seems to prevail in the lake's watershed. My study has not necessarily disproven the hypothesis put forward by Romme and Knight, but does cast some doubt. At least in the short-term, Yellowstone and Lewis Lakes appear to be relatively unaffected by fire disturbance of approximately a quarter of their watershed.

The large size of these lakes in comparison to their watersheds appears to be diluting the effect of any increased inputs. The relative importance of land-water interactions in affecting the productivity and water quality of Yellowstone's large lakes must be viewed in the context of a multitude of other factors, such as changing climate, atmospheric deposition, hydrothermal inputs, and even fisheries policy through the "top-down" or biological control of lake productivity.

From the perspective of an environmental scientist (someone often looking for bad news), my results (or lack of results) may be construed as disappointing. In other words, the 1988 fires didn't have any major impacts on Yellowstone's lakes. On the other hand, from the perspective of someone who treasures pristine subalpine lakes, my results are good news. Yellowstone's major lakes have weathered the fires pretty much intact.

Richard Lathrop, Jr., an Assistant Professor in the Department of Natural Resources at Rutgers University, New Brunswick, New Jersey, has studied Yellowstone lakes for several years.