

Alkalization of a High-Elevation Sierra Nevada Stream

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The construction of two bridges on Rock Creek, a high elevation stream in the Sierra Nevada, resulted in the elevation of stream water pH, conductivity, alkalinity, and calcium concentrations. Relative to an upstream unaffected site, the following maximum increases were observed: pH from 6.83 to 11.22, conductivity from 9 to 341 $\mu\text{S cm}^{-1}$, alkalinity from 70 to 2001 $\mu\text{eq L}^{-1}$, and calcium from 54 to 2227 $\mu\text{eq L}^{-1}$. Major effects were likely the result of the leaching of calcium oxide hydration products from cement in the bridge structures. Chemical effects proved to be transitory, lasting less than 1 day past the time of concrete pouring. Observed chemical changes may have had a detrimental effect on the stream biota and suggest that great care should be taken to isolate concrete structures from contact with poorly buffered surface waters during the period of cement hardening.

INTRODUCTION

Most studies of the effects of road and bridge construction on streams have concluded that observed changes in stream chemistry are small relative to changes in parameters such as turbidity, suspended solids, and channel sedimentation with some authors reporting up to a 40fold increase in suspended solids [Barton, 1977; Cline *et al.*, 1982]. Fewer studies have reported substantial effects on water chemistry. Burton *et al.* [1976] noted increases in total phosphorus and dissolved silica in a north Florida stream. Extence [1978] observed increases in iron associated with increased suspended solids in the River Roding in Great Britain, and Peterson and Nyquist [1972] attributed increased conductivity to bridge construction on a sub-Arctic stream in Alaska. Huckabee *et al.* [1975] reported the unanticipated acidification of a stream in the Great Smoky Mountains when road construction exposed rock containing mineralizable sulfides. In the present study we observed major changes in the chemistry of a Sierra Nevada stream concurrent with road improvement activities. We present data relating these changes to materials used in the emplacement of bridges across the stream.

METHODS

This study was conducted on Rock Creek, which lies on the eastern flank of the Sierra Nevada within the Inyo National Forest between Mammoth and Bishop, California (Figure 1). From the valley floor at 2160 m, the creek drains a basin extending to 4190 m in elevation. The upper portion of the basin is underlain by Mesozoic grano-diorites with large areas of exposed bedrock and shallow soils. Quaternary glacial deposits surround the lower portion of the stream (<2800 m) [Strand, 1967].

There were three types of sample collections, identified as bridge surveys, altitudinal surveys, and synoptic surveys. Stream samples collected from sites 1 through 8 constituted the Rock Creek Bridge Survey (Figure 1, Table 1). Sampling

sites for these collections included stations immediately above and below the installation points of two concrete bridges. Rock Creek altitudinal surveys were conducted from sites 7 through 15, from the inlet of Rock Creek Lake to Tom's Place. Two Rock Creek Synoptic Surveys were conducted at the inlet of Rock Creek Lake (site 7), 6383 m downstream from the lower and 7335 m downstream from the upper bridge. For the synoptic surveys, samples were collected sequentially at site 7 approximately every 20 min for 5 hours on September 9, 1983, and hourly for 6 hours on September 12, 1983. The chronology of our sample collecting activities is given in Table 2.

Water samples were collected in linear polyethylene bottles. The pH was measured electrometrically [Galloway *et al.*, 1979] using a Radiometer Ion 85 meter except on September 8, 1983, when pH was determined at the field site using a Fisher Accumet model 640A portable meter. Conductivity [American Public Health Association, APHA, 1980] was measured on a YSI model 58 meter and alkalinity (acid neutralizing capacity) by Gran's titration [Driscoll and Bisogni, 1984] using a Radiometer ABU80 autotitrator. We performed cation analyses using flame atomic absorption spectroscopy [APHA, 1980] on a Perkin-Elmer model 5000 instrument.

RESULTS

On August 23, 1983, samples were collected for chemical analysis from Rock Creek for comparison to stream and lake data which we were gathering as part of an integrated watershed study within the nearby Eastern Brook Lakes Watershed (EBLW) (see Figure 1). From previous results from the EBLW study we expected waters from Rock Creek to be near neutral in pH and poorly buffered. Therefore it was quite unexpected when a sample collected from the inlet of Rock Creek Lake exhibited a pH of 8.4 and elevated conductivity and alkalinity values (Figure 2). U. S. Forest Service (USFS) records indicate that on that date concrete footings were poured for the lower of two bridges being constructed (Table 2). Initially, we did not know the cause of the anomalous stream chemistry data; the lower bridge was 6383 m upstream and 118 m higher in elevation than the inlet and other activities were occurring along the stream at various camping areas and pack stations. The high pH value of the stream water suggested the presence of dissolved carbonate and possibly hydroxide in a basin containing no naturally occurring carbonaceous soils or rocks.

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TABLE 1. Rock Creek Sampling Sites

Site Number	Elevation, m	Downstream Distance, m	Name	Rock Creek Bridge Survey	Rock Creek Altitudinal Survey	Rock Creek Synoptic Survey
1	3118	0	Above Mosquito Flat	X		
2	3115	273	Below Mosquito Flat	X		
3	3100	918	Below Upper Bridge	X		
4	3091	1870	Below Lower Bridge	X		
5	3024	3733	Above Junction	X		
6	3022	5721	Above Waterfall	X		
7	2973	8253	Rock Creek Lake Inlet	X	X	X
8	2950	8995	Rock Creek Lake Outlet	X	X	
9	2865	nd	Rock Creek Lodge Lake		X	
10	2835	nd	Rock Creek Lodge Bridge		X	
11	2964	nd	East Fork		X	
12	2571	nd	Iris-Big Meadow		X	
13	2440	nd	Lower Aspen		X	
14	2283	nd	Above French Camp		X	
15	2158	nd	Tom's Place		X	

Chemical analyses of samples from a bridge survey on September 1 gave almost no indication of the large changes in stream chemistry observed less than 24 hours before. In addition, an altitudinal survey completed on September 6 showed no indication of construction effects. Rather pH, conductivity, alkalinity, and cation concentrations tended to increase with decreasing elevation (Figure 5).

The results of a synoptic survey of September 9 demonstrated the transitory nature of chemical effects of bridge construction on Rock Creek. Forest Service records indicate that concrete was poured at the upper bridge on this date (Table 2). The pH gradually increased throughout the day as measured on a field pH meter while conductivity, alkalinity and calcium values increased markedly at 12:20 PDT and later gradually decreased (Figure 6). Although lower in magnitude, magnesium concentrations showed a similar response whereas sodium and potassium concentrations did not appear affected by the concrete pouring.

During the second synoptic survey on September 12, pH and conductivity values remained within 0.04 units and $0.9 \mu\text{S cm}^{-1}$, respectively, over a 6-hour period reflecting the low daily variation in stream chemistry in the absence of outside

impacts. Additional bridge surveys conducted on September 21, 1983, and August 16, 1984, also gave no indication of residual effects of the construction activities on the stream chemistry of Rock Creek.

DISCUSSION

The concrete used in constructing the two bridges on Rock Creek, purchased from two plants in the Mammoth area, was of a standard commercial "Redi-Mix," and on dates after August 23, 1983, contained an admixture of Pozzolith 344-N (M. J. Calvert, U.S. Forest Services, personal communication, 1984). The concrete contained a Portland cement which is formed by mixing together calcareous and argillaceous materials, burning them at a high temperature, and grinding the resulting clinker [Lea, 1971]. Typical analyses for Portland cements in California give the following composition: 64–66% CaO, 22–23% SiO₂, 3.5–4.5% Al₂O₃, and 2.5–3.5% FeO (J. Young, Riverside Cement, personal communication, 1984). The setting and hardening of Portland cement are complex processes [Lea, 1971]. During the initial stages of setting, a supersaturated solution forms from which a gellike mass of crystals precipitate. A major step in the process is the hy-

TABLE 2. Chronology of Sampling and of Concrete Pouring on Rock Creek

Date	Sample Collections			Concrete Pouring*	
	Rock Creek Bridge Survey	Rock Creek Altitudinal Survey	Rock Creek Synoptic Survey	Lower Bridge	Upper Bridge
Aug. 17, 1983				X	
Aug. 19, 1983				X	
Aug. 23, 1983		X		X	
Aug. 26, 1983	X			X	X
Aug. 29, 1983	X				
Aug. 31, 1983	X	X			X
Sept. 1, 1983	X				
Sept. 6, 1983	X				
Sept. 9, 1983			X		X
Sept. 12, 1983			X		
Sept. 21, 1983	X				
Aug. 16, 1984	X				

*Information from Inyo National Forest, U.S. Forest Service, Bishop, California.

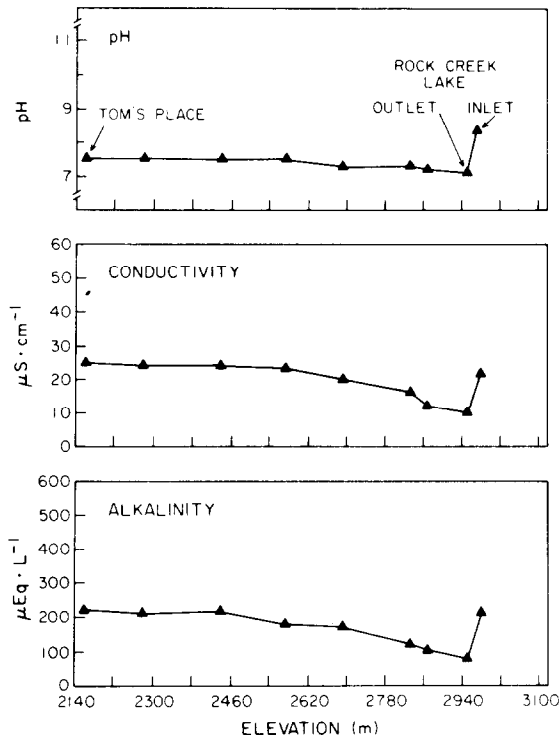


Fig. 2. Rock Creek Altitudinal Survey, August 23, 1983: pH, conductivity, and alkalinity versus elevation.

dration of oxides within the cement. Our analyses of Rock Creek waters indicate that some of the hydration products were released to the stream and greatly affected stream chemistry. In particular, the release of $\text{Ca}(\text{OH})_2$, the hydration

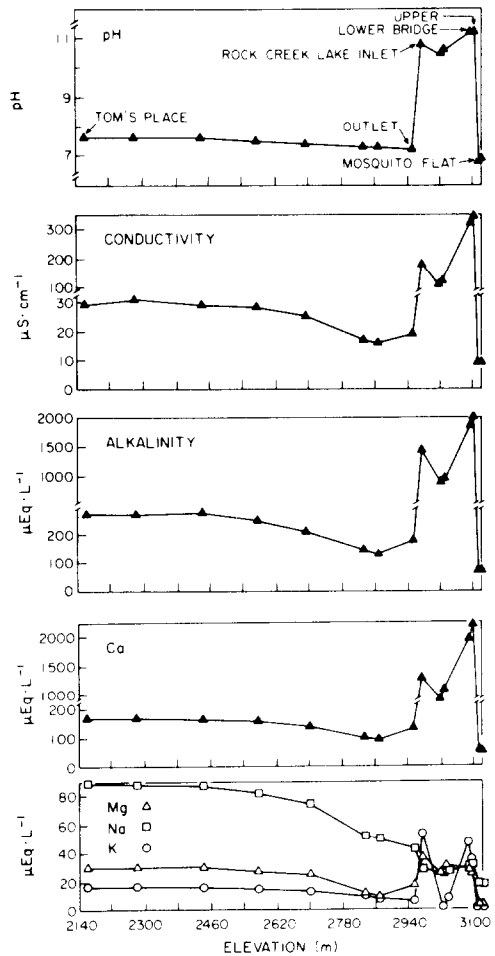


Fig. 4. Rock Creek Altitudinal and Bridge Survey, August 31, 1983: pH, conductivity, Ca, Mg, Na, and K versus elevation.

product of calcium oxide, appears to have been the major mechanism in altering the pH and alkalinity of the stream.

Typical landscapes at high elevation in the Sierra Nevada contain shallow soils and areas of exposed siliceous bedrock. The primary bedrock types in the region are composed primarily of granitic and metamorphic rocks of Mesozoic age [Jennings, 1977]. Surface waters in regions of shallow soils and siliceous bedrocks are characteristically very poorly buffered [Likens et al., 1979]. Recent surveys of over 200 lakes in the Sierra Nevada have found that most were near neutral in pH and had summer alkalinity values of $<200 \mu\text{Eq L}^{-1}$ with the majority having alkalinity values $<100 \mu\text{Eq L}^{-1}$ [El-Amamy et al., 1984; Melack et al., 1982; Tonnessen, 1984]. Freshwater ecosystems in such regions are believed to be particularly susceptible to effects of acidic deposition [Likens et al., 1979] and as our findings at Rock Creek demonstrate, waters in such circumstances also can be highly susceptible to alkalization.

Studies on the effects of construction activities on stream biota have generally attributed observed effects to siltation and turbidity problems [Extence, 1978; Lenat et al., 1981; Cline et al., 1982]. Although we do not have quantitative sediment data for Rock Creek, we did observe that stream improvement activities in preparation for the bridge emplacements produced large sediment plumes extending at times across most of the length of Rock Creek Lake (670 m).

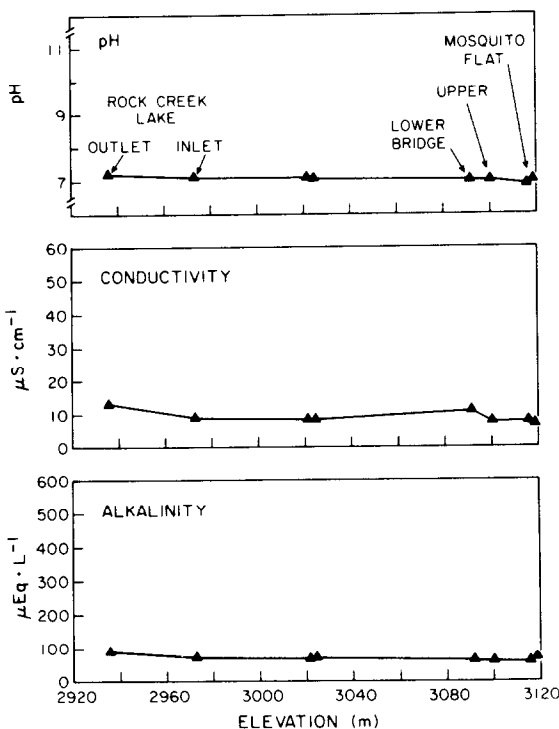


Fig. 3. Rock Creek Bridge Survey, August 26, 1983: pH, conductivity, and alkalinity versus elevation.

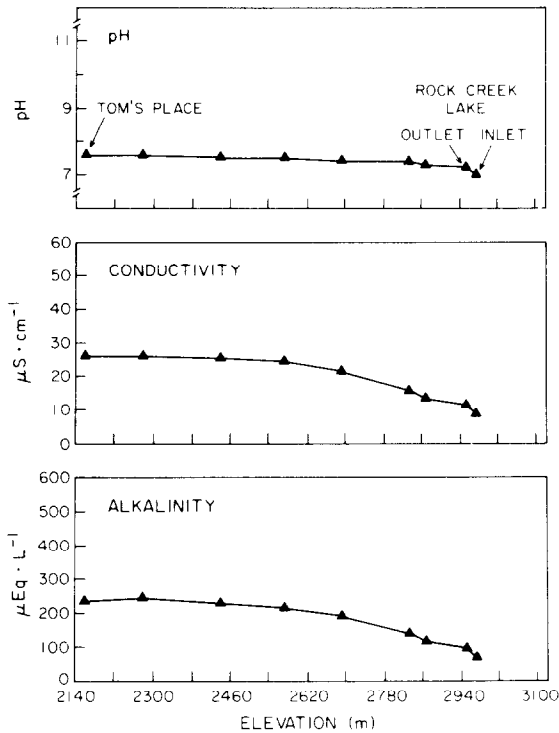


Fig. 5. Rock Creek Altitudinal Survey, September 6, 1983: pH, conductivity, and alkalinity versus elevation.

The effects of elevated pH levels on freshwater organisms have not been investigated extensively and only a few toxicological studies have been conducted on aquatic invertebrates [Lechleitner et al., 1985]. However, in toxicological tests on fish, 50% lethal concentration values (LC_{50}) for salmonids have been reported in the pH range of 9–10 and above pH 11 few fish survived even short-term exposures [Alabaster and Lloyd, 1980]. We therefore suspect that the high pH values and sediment loads which we observed in our study might have produced detrimental effects on the biota of Rock Creek, a popular trout fishing stream.

The transitory nature of the effects at Rock Creek explain why the alkalinization of streams associated with concrete use has not been previously reported. The results demonstrate that our detection of effects required sampling to occur immediately during or shortly after the time that concrete was poured. Our observations suggest that stream chemistry changes from these activities may be commonplace, particularly in streams with poorly buffered waters. Biologic effects previously attributed to sedimentation in some cases may have been the result of unnoticed changes in stream chemistry.

Further study is needed to quantify the extent of possible biologic effects of such alkalinization events. Our results indicate that greater care should be taken to isolate concrete structures from the water column during the hardening process. The synoptic survey data suggest that field measurements of conductivity could be used as a sensitive indicator of stream contamination. Finally, our data indicate that concrete structures, once the cement has hardened, do not have a long-term impact on stream pH, alkalinity, conductivity, and major cation chemistry.

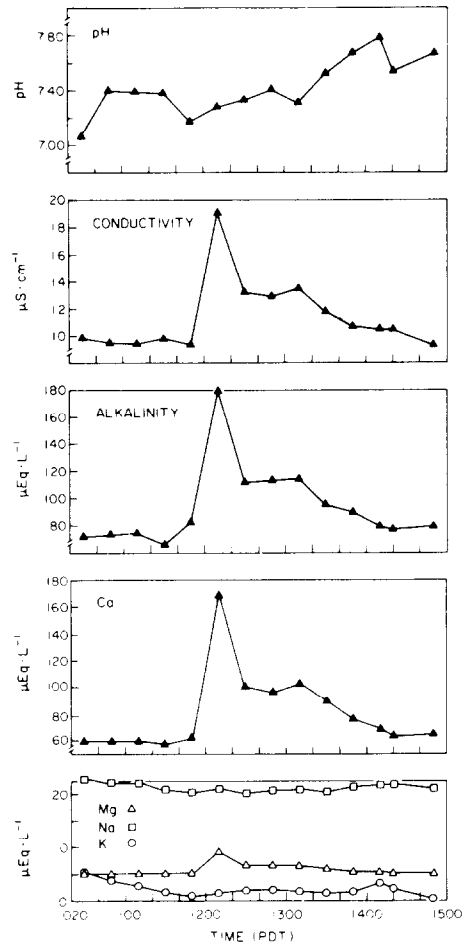


Fig. 6. Rock Creek Synoptic Survey, September 9, 1983: pH, conductivity, and alkalinity, Ca, Mg, Na, and K versus elevation.

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