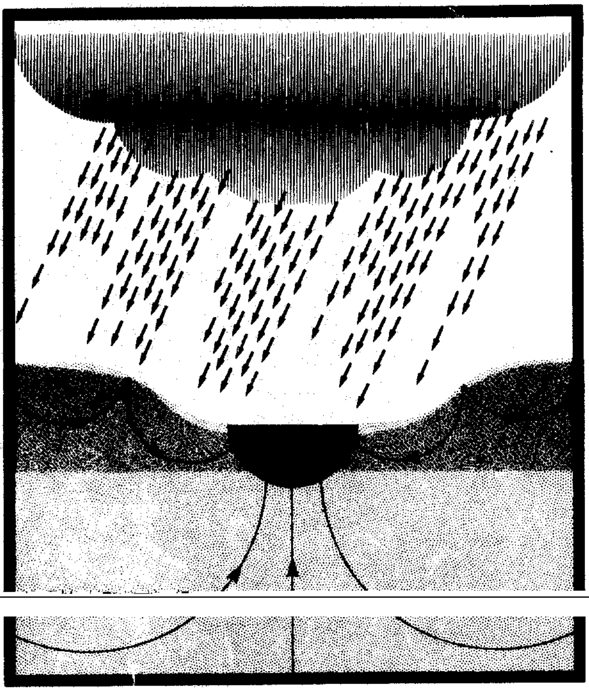
Acidification and Water Pathways



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PROCESSES AFFECTING THE CHEMISTRY OF WATERS PASSING THROUGH A HIGH ELEVATION SIERRA NEVADA WATERSHED.

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ABSTRACT

The Eastern Brook Lakes Watershed is located in the Sierra Nevada Mountains of California and spans an elevational range from 3060 to 3780m. Changes in stream and lake chemistries along spatial and temporal flowpaths demonstrate that both terrestrial and aquatic processes were important in regulating surface water chemistries within the 250 ha watershed. Streams generally showed increasing pH, alkalinity, and conductance values with decreasing elevation. Large changes in stream chemistries occurred over short distances at locations such as alpine meadows. During the spring , stream alkalinities and conductance values decreased while stream pH values increased with time. pH values reached their maximum in June when alkalinity and conductance values were at their minimum values.

Internal lake processes strongly influenced the chemistry of Upper Eastern Brook Lake. During spring and summer, lake waters exhibited near-neutral pH, low conductance (10-12 $\mu S \cdot cm^{-1}$), low alkalinity (100-120 $\mu Eq \cdot L^{-1}$), and undetectable ammonium. Under the ice, major changes in lake chemistry occurred associated with oxygen depletion in the hypolimnion. pH values decreased with time towards a minimum of 6.3 at 6m depth. Other parameters increased with time and depth under the ice, reaching maximum values as follows: conductance > 80 $\mu S \cdot cm^{-1}$, Gran's alkalinity > 370 $\mu Eq \cdot L^{-1}$, and ammonium > 50 $\mu Eq \cdot L^{-1}$.

INTRODUCTION

Extensive surveys of over 200 lakes in the Sierra Nevada Mountains of California have shown that most were near neutral in pH and had summer alkalinity values < 200 $\mu Eq \cdot L^{-1}$ with the majority having alkalinity values < 100 $\mu Eq \cdot L^{-1}$ (El-Amamy et al., 1987; Melack et al., 1982; Tonnessen, 1984). Freshwater ecosystems in such regions are believed to be particularly susceptible to the effects of acidic deposition (Likens et al., 1979). The Eastern Brook Lakes Watershed (EBLW) Study was established to evaluate the potential long-term effects of acidic deposition to surface waters in the region.

The EBLW spans an elevational range from 3060 to 3780m (Figure 1). The 250 ha watershed (118°44'W, 37°26'N) contains granitic alpine zones, meadows, pine forests, streams, and lakes. Although a major portion of the watershed consists of exposed granitic slopes, extensive areas within the lower watershed surrounding the lakes contain poorly developed soils, the majority of which have been classified as Cryochrepts in the American system of soil taxonomy. Acidic deposition does occur at EBLW although deposition rates are low compared to eastern North America and Europe. During 1985, 52 $Eq \cdot ha^{-1}$ of hydrogen ion and 563 mm of wet precipitation were deposited at the EBLW meteorologic site giving a weighted average pH for the precipitation of 5.04.

METHODS

Upper Eastern Brook Lake was sampled approximately biweekly during the interval of August 1983 through July 1985 at a sampling station located above the point of maximum depth (z_{max} = 9m, Figure 1.). Dissolved oxygen and temperature were measured at half meter intervals using a YSI oxygen meter. Water samples were taken, using a Scott Bottle, at the surface, 0.5m and at 1m intervals thereafter to a depth of 8m. Streams in the upper watershed were sampled when possible depending upon snow conditions. Major lake inlets and the lake outlet were sampled weekly when access permitted. Elevational samples from the two inlet streams were collected during the snow-free period.

Samples were collected in linear polyethylene bottles and analyzed at the Sierra Nevada Aquatic Research Laboratory, Mammoth Lakes, California. Analytical methods for pH, conductance, and Gran's alkalinity were described in Nodvin et al. (1986). Ammonium was measured colorimetrically (American Public Health Association, 1980) and dissolved organic carbon (DOC) by the method of Stainton (1973).

Results from the lake and stream surveys were interpreted through the construction of isopleth diagrams of lake properties and surface response plots of stream chemistries. Surface response plots presented here represent chemical gradients from the headwaters of the

West Inlet (3220m) to the Outlet (3100m) of Upper Eastern Brook Lake during summer and autumn of 1985. The lake and stream data were gridded using the Kriging algorithm (Kilroy, 1981) and plotted using a personal computer software package (Golden Software, 1987).

RESULTS AND DISCUSSION

The results of the stream analyses suggest that major factors regulating stream chemistry were the flow path of waters passing through the terrestrial system, the time of contact of waters with the soil and other substrates, and the relative contributions of snowmelt and subsurface flow to the streams. The two major streams showed increasing pH, alkalinity, conductance and DOC values with decreasing elevation during the spring and autumn when discharge rates were relatively high (Figures 2 and 3). During the dry summer period, maximum values for these parameters were found at mid-elevations. Large changes in stream chemistry were observed over short distances at certain locations such as alpine meadows. Chemical parameters at the lake outlet remained more constant through the summer season than those measured in the inlet streams.

During the spring melt period, alkalinity, conductance and DOC values at the East and West Inlets decreased while pH values increased with time (not shown). Declining conductance and anion values during this time suggest that the observed trend in alkalinity values was the result of dilution of base flow stream water with dilute snowmelt waters.

In June, inlet pH values reached a maximum and then began to drop. Alkalinity and conductance measurements reached minimum values in June and then increased during the dry summer period. Inlet DOC values tended towards minimum values during the summer. Alkalinity and conductance values decreased again in the autumn during the time of renewed precipitation activity.

Eastern Brook Lake exhibited large seasonal changes in lake chemistry related to changes in the oxygen status of the lake. Summer periods were characterized by moderate thermal stratification, near neutral pH values, conductance values near 11 $\mu S \cdot cm^{-1}$, and Gran's alkalinity values near 100-120 $\mu Eq \cdot L^{-1}$ (Figures 4 and 5). A depression in bottom water oxygen tension was observed in the summers of 1984 and 1985. Otherwise, the summer periods had minimal stratification in other chemical parameters.

Lake conditions under the ice were characterized by inverse thermal stratification with deep waters exhibiting temperatures greater than 4°C (due to the formation of strong chemical density gradients) and by strong oxygen gradients (Figure 4). Depths below 6m became anoxic by mid-winter and pH values tended to decrease with time establishing a pH minimum near 6.3 at 6m depth. Once the bottom layers became anoxic, in December and January, large vertical conductivity gradients formed. The strongest stratification occurred in March or April when surface waters showed conductance values between 18 and 20 $\mu S \cdot cm^{-1}$ and bottom waters greater than 75 $\mu S \cdot cm^{-1}$. At that time surface alkalinity values ranged between 140-160 $\mu Eq \cdot L^{-1}$ and bottom water values exceeded 380 $\mu Eq \cdot L^{-1}$. Ammonium, which was undetectable during the summer months, developed a strong vertical stratification with bottom waters exceeding 50 $\mu Eq \cdot L^{-1}$.

The work presented here evaluated spatial and temporal changes in stream and lake chemistries. The results demonstrate that both terrestrial and aquatic flowpaths and processes are important in regulating the chemistry of surface waters in the Sierra Nevada. Chemical trends along elevational gradients indicate that water flowpaths and residence times within the terrestrial system greatly influence surface water chemistries. Weathering processes within the soil are likely a major source of alkalinity (see Feth et al., 1964). The association of major changes in lake chemistry with the oxygen status of the lake indicates that internal lake processes and especially oxidation-reduction reactions can exert a major influence on the chemistries of Sierra Nevada lakes.

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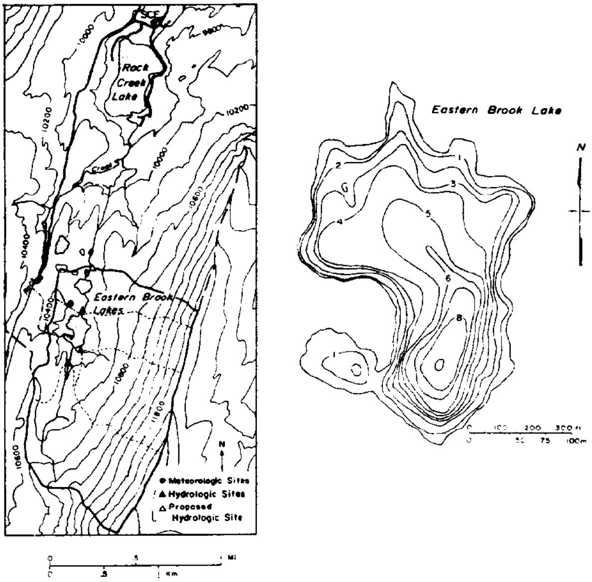

Figure 1. Topographic map of the Eastern Brook Lakes Watershed (elevations in feet) and hypsographic map of Upper Eastern Brook Lake (depth contours in meters).

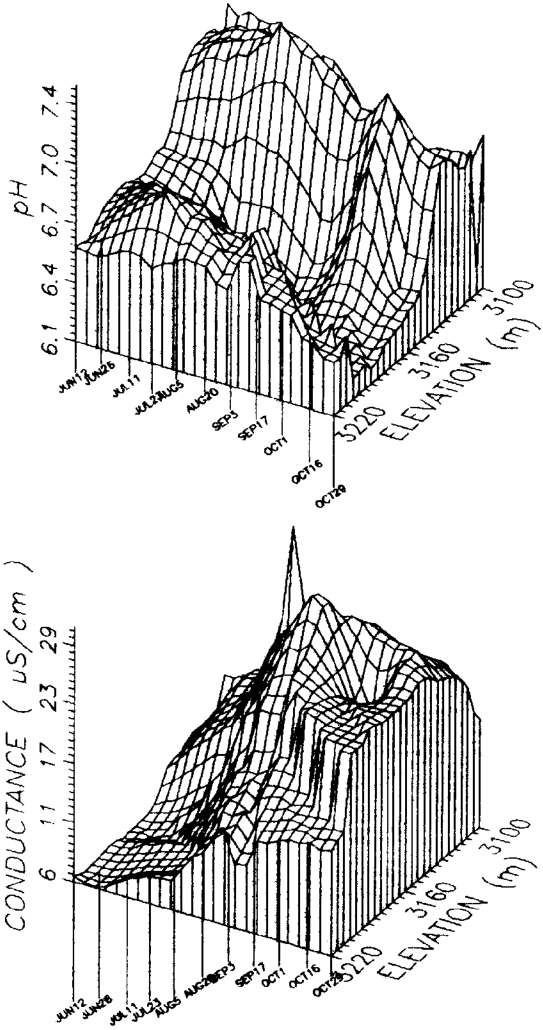

Figure 2. Surface response plots of pH (closed) and conductance with time and elevation for the West Inlet and Outlet of Upper Eastern Brook Lake during 1985.

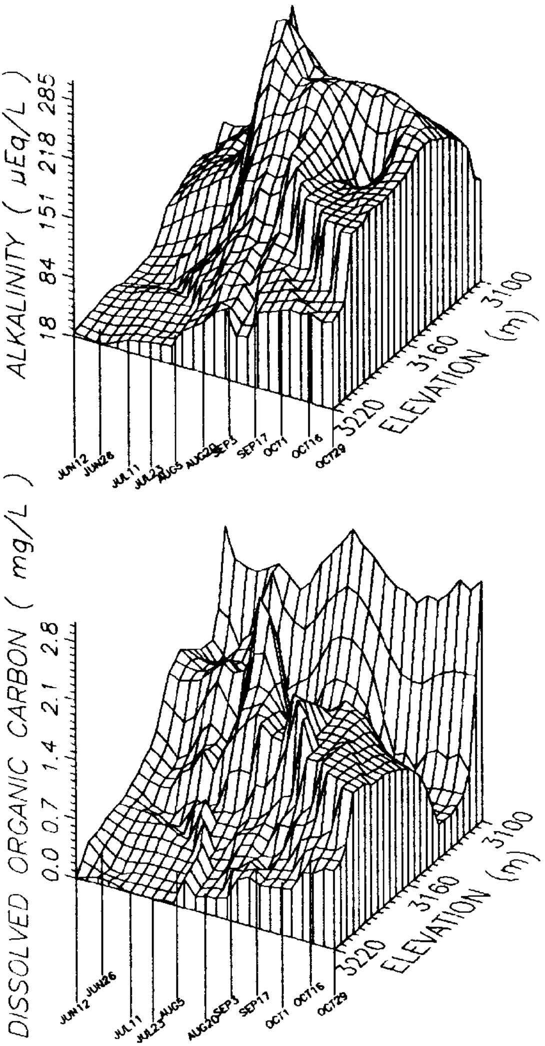

Figure 3. Surface response plots of alkalinity and dissolved organic carbon with time and elevation for the West Inlet and Outlet of Upper Eastern Brook Lake during 1985.

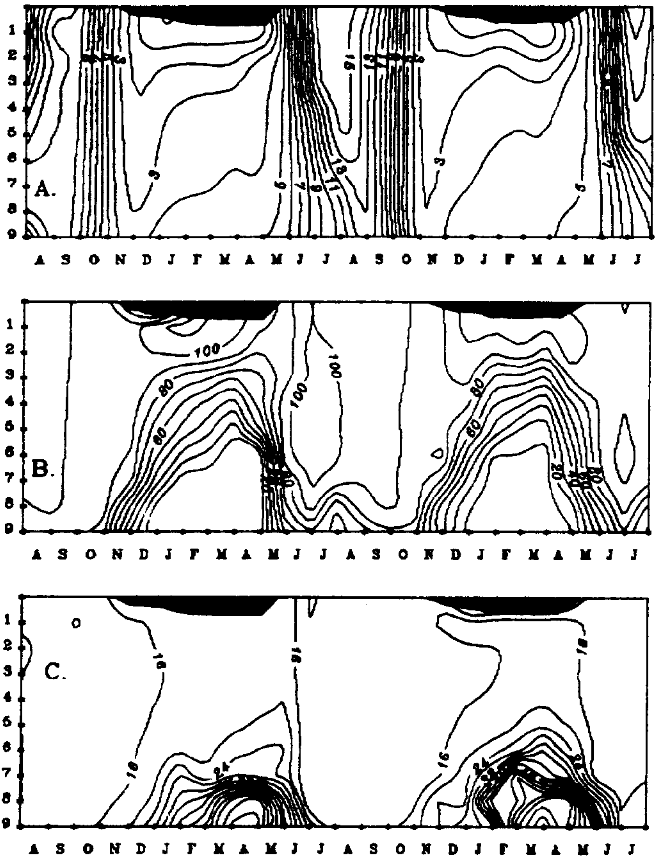

Figure 4. Isopleth diagrams for Upper Eastern Brook Lake for the period of 1 August 1983 to 31 July 1985: A. Temperature (°C), B. Percentage oxygen saturation, C. Conductance ($\mu S \cdot cm^{-1}$). Darkened areas represent ice cover.

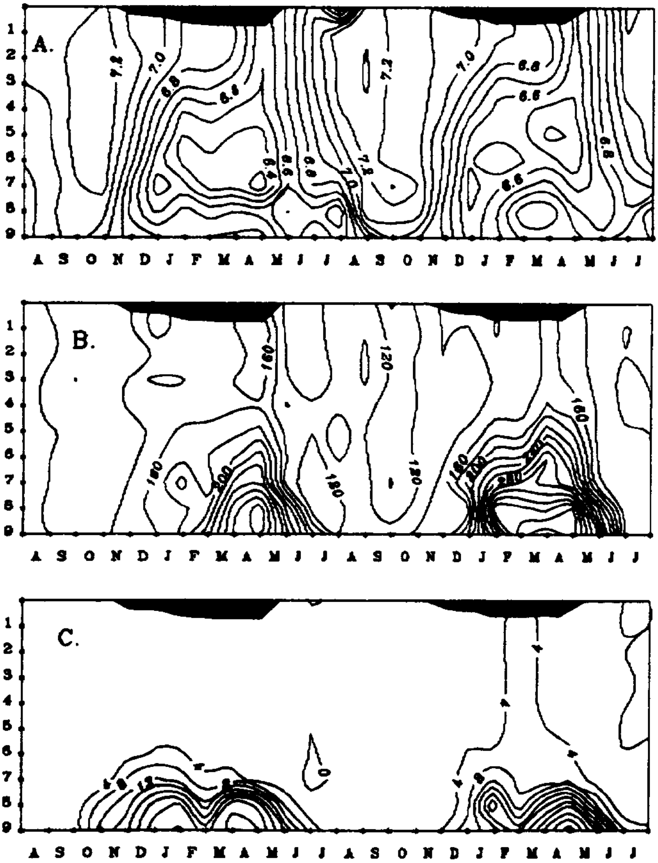

Figure 5. Isopleth diagrams for Upper Eastern Brook Lake for the period of 1 August 1983 to 31 July 1985: A. pH (closed), B. Alkalinity ($\mu Eq \cdot L^{-1}$, C. Ammonium ($\mu Eq \cdot L^{-1}$). Darkened areas represent ice cover.