ASSESSING THE SENSITIVITY OF HIGH ALTITUDE NEW MEXICAN WILDERNESS LAKES TO ACIDIC PRECIPITATION AND TRACE METAL CONTAMINATION

By

Thomas R. Lynch
Co-Principal Investigator
Department of Biology
New Mexico Institute of Mining and Technology

Carl J. Popp
Co-Principal Investigator
Department of Chemistry
New Mexico Institute of Mining and Technology

Gerald Z. Jacobi
Co-Principal Investigator
School of Science and Technology
New Mexico Highlands University

and

James Robertson
Co-Principal Investigator
New Mexico Bureau of Mines and Mineral Resources

TECHNICAL COMPLETION REPORT

Project Number 1423697
U.S. Geological Survey Grant Number 14-08-0001-G1505

November 1988

New Mexico Water Resources Research Institute

The research on which this report is based was financed in part by the U.S. Department of the Interior, Geological Survey, through the New Mexico Water Resources Research Institute.

The purpose of Water Resources Research Institute technical reports is to provide a timely outlet for research results obtained on projects supported in whole or in part by the institute. Through these reports, we are promoting the free exchange of information and ideas and hope to stimulate thoughtful discussion and actions that may lead to resolution of water problems. The WRRI, through peer review of draft reports, attempts to substantiate the accuracy of information contained in its reports, but the views expressed are those of the author(s) and do not necessarily reflect those of the WRRI or its reviewers. Contents of this publication do not necesarily reflect the views and policies of the U.S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States government.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

We would like to extend our sincere gratitude to the following for their appreciated assistance: the U.S. Geological Survey (USGS) and the New Mexico Water Resources Research Institute for financial support; the U.S. Forest Service for financial and field logistic support; Jim McCarthy, New Mexico Institute of Mining and Technology, for field assistance in sampling Santa Fe Lake; Deborah Potter, New Mexico Environmental Improvement Division, for zooplankton identification and enumeration; Dan Davis and Scott Hopkins, students from New Mexico Highlands University, for participation in sample collection and data analysis; Tim Peter, Stacy Stowe, Sandy Svec, David Whaley, and Jacqueline Zody, students at New Mexico Institute of Mining and Technology, for participation in sample collection and data analysis; Leo Smith and Bill Mundy for arranging access to lakes located on private land; Mike Evans and the Santa Fe Ski Basin for allowing access to ski lifts for winter sampling of Santa Fe Lake; Taos Ski Valley for access to Williams Lake; Austin Long for sulfur isotope analysis; and Susan G. Britvec and Debby Olguin of New Mexico Institute of Mining and Technology for typing and manuscript preparation. We would also like to thank Deborah Potter and Dr. James Brierley for providing a technical review of an earlier draft.

ABSTRACT

Seventeen high mountain lakes in northern New Mexico were sampled to determine their present biological and chemical condition. In addition, sediment cores were collected at each of the lakes to determine trace metal concentrations, diatom assemblages, and mineralogies as a function of depth. Two of the cores were age-dated using Pb-210 chronology. Eight of the lakes exhibited low alkalinities and, therefore, low capacities for neutralization. These lakes were located in basins where the surface geology was cominated by Precambrian rocks. Atmospheric deposition appears to be contributing acid and trace metals associated with anthropogenic sources to some of the lakes. Trace metal accumulations in the upper layers of Santa Fe Lake began about 60 years ago and about 10 years ago in Truchas Lake. An acid pulse (pH 5.7) associated with snow melt was documented in Santa Fe Lake and correspond with an observed decrease of <u>Daphnia</u> sp. populations. Pea clam densities also appeared to be lower in the low alkalinity lakes. Sediment diatom assemblages in cores from Santa Fe Lake and Truchas Lake appear to be shifting to more acid tolerant species than in the past.

Key words: acid precipitation, diatoms, heavy metals, geochemistry, trace metals, water quality

INTRODUCTION

Much of the concern related to the environmental impact of acidic precipitation has focused on areas east of the Mississippi River, particularly in the upper Midwest, New England, and southeastern Canada. Acidic precipitation was not considered a problem in the West primarily because data documenting the occurrence of acidic precipitation were nonexistent. Evidence that acidic precipitation is a potential problem in various parts of the West has been mounting. In recent years, acidic precipitation events have been detected with regularity in the Sierras (Melack et al. 1983), the Cascades (Logan et al. 1982), central Colorado (Lewis and Grant 1980), and in northern and central New Mexico (Popp et al. 1982; Popp et al. 1984; Popp et al. 1986).

Ecosystems of the Southwest and intermountain West were considered nonsusceptible to the effects of acidic precipitation because lowland soils are typically alkaline and, therefore, should have a large capacity for neutralization of dilute acids. In addition, regional emissions of acid precursors were thought to be low. Regional assessments of acid neutralizing capacity were developed on the basis of studies using large scale geological maps (Galloway et al. 1983; Turk 1983) which often failed to predict the considerable heterogeneity of aquatic ecosystem susceptibility observed in a more localized analysis (Electric Power Research Institute 1983; Eilers et al. 1983).

The high mountain watersheds of northern New Mexico and southern Colorado may be particularly vulnerable to acidic precipitation for a number of reasons. Acidic precipitation has been documented for the entire length of the Rocky Mountains in Colorado (Lewis et al. 1984; Turk and Adams 1983; Harte et al. 1985). The lowest mean pH values in a statewide survey of 42 sites in Colorado conducted in 1982-83 were less than 5.0 and were found near the Continental Divide in the northern third and southern third of the state

(Lewis et al. 1984). Precipitation in northern and central New Mexico has a pH that averages 4.7 to 5.5 on an event basis and from 4.0 to 4.9 on a volume-weighted basis (Popp et al. 1982; Popp et al. 1984). The difference between these data sets indicates that larger precipitation events input larger quantities of acids than small volume events. The major reason for this is that atmospheric particles of terrestrial origin help neutralize the acidity associated with low volume events (Popp et al. 1982; Popp et al. 1984). These neutralizing dust particles tend to be flushed out early; thus, the longer the duration of a precipitation event, the greater the input of unneutralized acids. In the mountains, concentrations of alkaline dust tend to be lower due to the higher altitude and the heavier vegetative cover. Dust has a less significant neutralization effect on the precipitation in these areas and the pH of the precipitation is generally lower in the mountains than in the valleys (Popp et al. 1982; Popp et al. 1984). In Colorado, air masses moving over mountains also show an increase in acidifying substances at higher elevations (Lewis et al. 1984). Stable isotope analysis for S-34/S-32 suggests that sulfate in precipitation in New Mexico may have a significant reduced source (i.e., sulfides) rather than entrainment of regional terrestrial sulfates (Popp et al. 1984).

The high altitude watersheds of northern New Mexico receive large quantities of precipitation relative to other locations within the arid Southwest (76-89 cm vs. 20-30 cm), primarily as snow during the winter and as intense thunderstorms during the summer. The soils of these high mountain watersheds are derived primarily from volcanic and granitic rocks (New Mexico Geological Society 1982). These are rock types that are characteristic of watersheds that have been acidified in other parts of the world primarily because they have low neutralization capabilities. The soils of high altitude mountainous watersheds are typically thin, poorly developed, and are located on steep gradients. These additional factors interact to allow only minimal contact time between percolating water and the scarce or absent acid-neutralizing components of the soils. Consequently, we hypothesize that the buffering capacity of the lakes within these watersheds is low.

The high elevation lakes examined in this study are located downwind from the Four Corners area of New Mexico, site of one of the largest coal-burning power plant complexes in the intermountain region. Power plants in the northwestern part of New Mexico currently consume more than 25,000 tons of coal per day. Coal combustion is increasing in the region and is projected to continue well into the next decade.

A point source emissions inventory compiled by the State of New Mexico Environmental Improvement Division (1982) indicates that sources in the northwestern region of the state produce 129,000 tons of SO_2 and 74,400 tons of $NO_{(x)}$ per year. The SO_2 emissions are approximately one-half of the total utility SO_2 emissions in the Four Corners states: Arizona, New Mexico, Colorado, and Utah (Niemann 1985). Even with the installation of additional pollution controls at the power plants, emission of acid precursors is likely to increase as plans to increase generating capacity in the region are implemented in coming years.

Emissions of acid precursors by non-ferrous metal smelters may also be impacting on these watersheds. Copper smelters in southeastern Arizona, southwestern New Mexico, and northern Mexico may be contributing significantly to the regional background of acid precursors (Oppenheimer et al. 1985). Point sources in Grant County, located in southwestern New Mexico where there are two large copper smelters, produce 74,400 tons of SO_2 per year (NMEID 1982). Data for Arizona and New Mexico smelter SO_2 emissions and for the Four

Corners states utility SO_2 emissions are summarized in table 1. Two smelters currently operate in northern Mexico, one at Cananea and one at Nacozari. The plant at Nacozari will emit 347,000 tons of SO_2 per year and is the subject of considerable negotiation over pollutant controls between the United States and Mexico. Copper smelting in Arizona and New Mexico has already been implicated as the cause of deteriorating air quality in the region (Ashbaugh 1984). Oppenheimer et al. (1985) demonstrated a relationship between SO_2 emissions from non-ferrous metal smelters in Arizona and New Mexico and subsequent changes in sulfate deposition at National Acid Deposition Program Stations in Colorado, Utah, and Arizona. In view of the existing and projected emissions of acid precursors, the potential exists for present and future acidification of high mountain watersheds in northern New Mexico. In addition, the lakes in these watersheds are in the most sensitive areas in the region and could constitute an early indication of potential acidification.

The distribution of lakes in the intermountain West vulnerable to ongoing inputs of acidic precipitation is not well known. Remote lakes at high altitude with low buffering capacities have been reported from Rocky Mountain National Park (Baron 1983), the Flat Tops Wilderness Area of northwestern Colorado (Turk 1983), and in the Elk Mountains of west central Colorado (Harte et al. 1985).

Based on the experiences of Sweden, Norway, New England, and southeastern Canada, the effects of acidification on aquatic environments are noticeable long before those occurring in terrestrial environments. In this respect, the lakes may serve as an early warning device of more devastating effects associated with declines in forest productivity. Summaries of this research have been compiled by Likens et al. (1979), Haines (1981), Dillon et al. (1984), and Schindler (1988).

TABLE 1

Sulfur Dioxide Emissions from Non-Ferrous Smelters in Arizona and New Mexico (NMEID 1988; Potter 1988) and from Utilities in the Four Corners States (Niemann 1985). Emissions in metric tons x 10^3

Source	1980	1981	1982	1983	1984	1985	1986
Arizona Smelter	579	794	374	446	560	---	397
New Mexico Smelter	122	145	129	181	100	250*	55
Four Corners States Utilities	234	254	285	275	181*	---	116*

* Arizona/New Mexico Coal
** New Mexico Total

The effects of acidification of lakes include increases in (1) transparency (Schindler et al. 1980; Kwiatkowski and Roff 1976; Yan 1983), (2) thermocline depth (Yan 1983), (3) epilimnetic thickness (Yan 1983), and (4) hypolimnetic heating rates (Yan 1983). Changes in aqueous chemistry typically involve (1) reductions in pH and neutralization capacity (Somers and Harvey 1984; Schindler et al. 1980; Hall et al. 1980; Galloway et al. 1983), (2) altered concentrations, speciation, and dynamics of sulfur species (Schindler et al. 1980), (3) increased concentrations of base cations (Hall et al. 1980; Galloway et al. 1983), and (4) increased concentrations of trace metals in solution (Somers and Harvey 1984; Schindler et al. 1980; Hall et al. 1980; Havas and Hutchinson 1982).

Effects of acidification on biological organisms and communities are variable, but the accumulating evidence indicates that the changes are predominantly detrimental. Schindler et al. (1980) did not detect any changes in chlorophyll a concentrations or primary production when they experimentally acidified a lake in southern Ontario. Kwiatkowski and Roff (1976), however, did detect a decrease in chlorophyll a concentrations with declining pH in a series of acidified lakes. These authors also noted a reduction in primary production in lakes having a pH less than 5.5. The pH of the lake that was acidified by Schindler et al. (1980) never dropped below 5.7, which may explain the discrepancy between the two data sets. Major changes in species composition, abundance, and diversity of phytoplankton communities have been reported for acidic lakes when compared to non-acidified lakes in the same area (Kwiatkowski and Roff 1976; Brezonik et al. 1984).

Zooplankton communities are also adversely affected by acidification, although it is difficult to determine whether the observed changes are due to direct effects or to effects brought on by changes in the phytoplankton community or the predatory fish community. Roff and Kwiatkowski (1977) found a significant reduction in the number of zooplankton species present, their population sizes, and the diversity of the community at low pH levels. Acidification also had a significant negative effect on zooplankton diversity and biomass in a study by Confer et al. (1983). Major shifts in species dominance within the zooplankton community were observed during both studies.

Organisms other than zooplankton are also adversely affected. Experimental acidification of a stream in the Hubbard Brook Experimental Forest of New Hampshire caused a major increase in the number of drifting immature aquatic invertebrates (Hall et al. 1980). This study also reported that acidification (1) lowered the emergence of adult mayflies, stoneflies, and dipterans, (2) caused decreased species diversity of aquatic insects, (3) decreased food web complexity, and (4) increased the relative abundance of community dominants.

The acidification of aquatic systems has been cited as a major causative agent of changes in fish communities. Reported effects range from loss of certain species (Somers and Harvey 1984; Beamish et al. 1975; Beamish and Harvey 1972; Rahel and Magnuson 1983) to total elimination of all fish species (Somers and Harvey 1984). Other effects that have been documented include (1) declines in abundance (Beamish and Harvey 1972), (2) declines in growth (Beamish et al. 1975), (3) increased incidence of spinal deformities (Beamish et al. 1975), and (4) changes in calcium metabolism (Beamish et al. 1975).

In addition to generating large quantities of SO_2 and $NO_{(x)}$ emissions, coal combustion and copper smelting release large quantities of trace metals into the atmosphere. Motor vehicles specifically generate Pb aerosols. Increases in the concentration of trace metals such as Zn, Cu, or V in the atmosphere generally result in increased bulk deposition onto terrestrial and aquatic environments downwind from the source (Somers and Harvey 1984; Evans et al. 1983). Whether deposited directly or moved to aquatic systems as the result of mass transport from the watershed, the trace metals eventually accumulate in bottom sediments. Analysis of vertical cores of lake bottom sediments for contaminants has proven to be a valuable technique for documenting chronological changes in regional atmospheric chemistry (Evans et al. 1983; Bertine and Mendeck 1978; Nriagu et al. 1982). Trace metals and industrial organic chemicals associated with upwind anthropogenic activities have been detected in the bottom sediments of remote wilderness lakes of Rocky Mountain National Park (Heit et al. 1984; Baron et al. 1986).

Increased trace metal toxicity to aquatic biota is often associated with increasing acidification (Haines 1981). There are two primary reasons for this: (1) increased atmospheric inputs of trace metals associated with industrial activities that are also generating the acid precursors; and (2) the increased solubility of sedimented trace metals with lower aqueous pH (Nriagu et al. 1982).

Clearly, acidification can cause significant biological changes. Such changes are pervasive and occur at the population, community, and ecosystem levels of organization. System structure and function are seriously altered resulting in new patterns of energy flow and biogeochemical cycling. The extent and impact of these changes have major implications for both aquatic and terrestrial systems as well as for the human species.

The specific objectives of this research project were to: (1) document the present pH and buffering capacity of a series of high mountain wilderness lakes; (2) determine the vulnerability of these lakes to future acidification as energy and mineral resource development intensifies in the four state region; (3) determine, using chemical and biological procedures, the loss of buffering capacity in the recent past as a result of acidic inputs; (4) establish via sediment cores a chronological record of trace metal deposition from atmospheric inputs as a function of increasing regional anthropogenic activity and the possible leaching of metals from poorly buffered watershed soils by dilute acids; and (5) study the monthly variation of pH and alkalinity in one lake as a function of precipitation inputs and biological activity.

MATERIALS AND METHODS

Sampling: Scope of Activities

During the summers of 1986, 1987, and 1988, a total of 17 lakes located in the Pecos Wilderness, Wheeler Peak Wilderness, and Brazos Uplift areas of northcentral New Mexico were sampled (figures 1 - 4). These lakes were generally at elevations exceeding 3000 m and, with the exception of those on the Brazos Uplift, were accessible only by foot. The Brazos Uplift lakes are on private ranch property managed for cattle grazing, trophy hunting, and fishing. The extent of human disturbance was, therefore, minimal in all areas. Horses were utilized as pack animals to transport instruments, sampling equipment, and samples in wilderness areas. Most of the lakes were sampled twice during two different summers. Santa Fe Lake was sampled monthly during 1987-1988. Sampling dates for each lake are indicated in table 2. At each lake, the surface geology of the basin was examined by two geologists (J. Robertson, T. Peter) who noted types and relative abundance of the exposed rocks as they hiked around the lakes.

All lakes were sampled extensively on the first visit for a variety of chemical and biological characteristics. An inflatable raft was used as a sampling platform. For determining lake volumes, depth soundings were taken

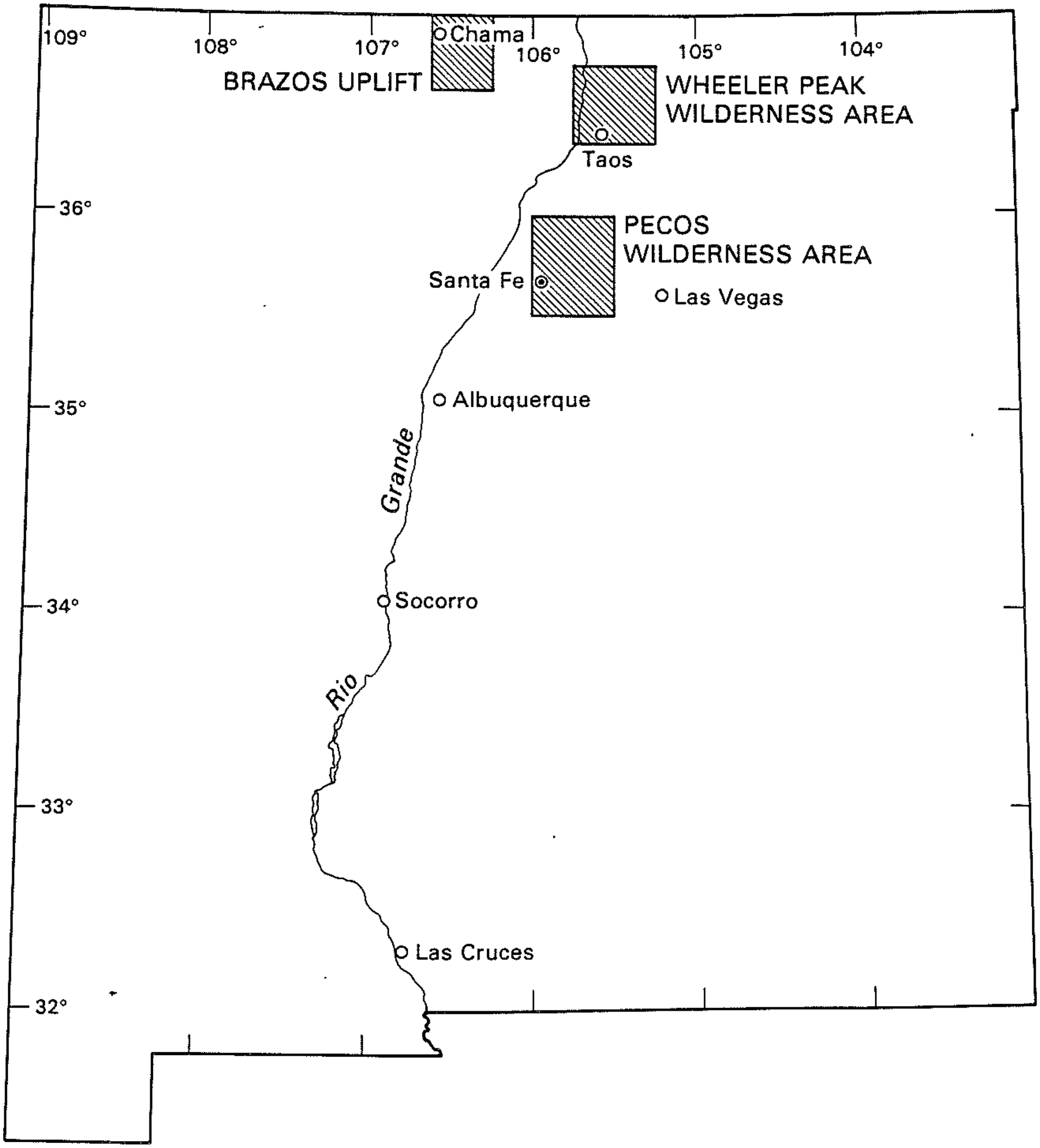


Fig. 1. Location of Study Areas

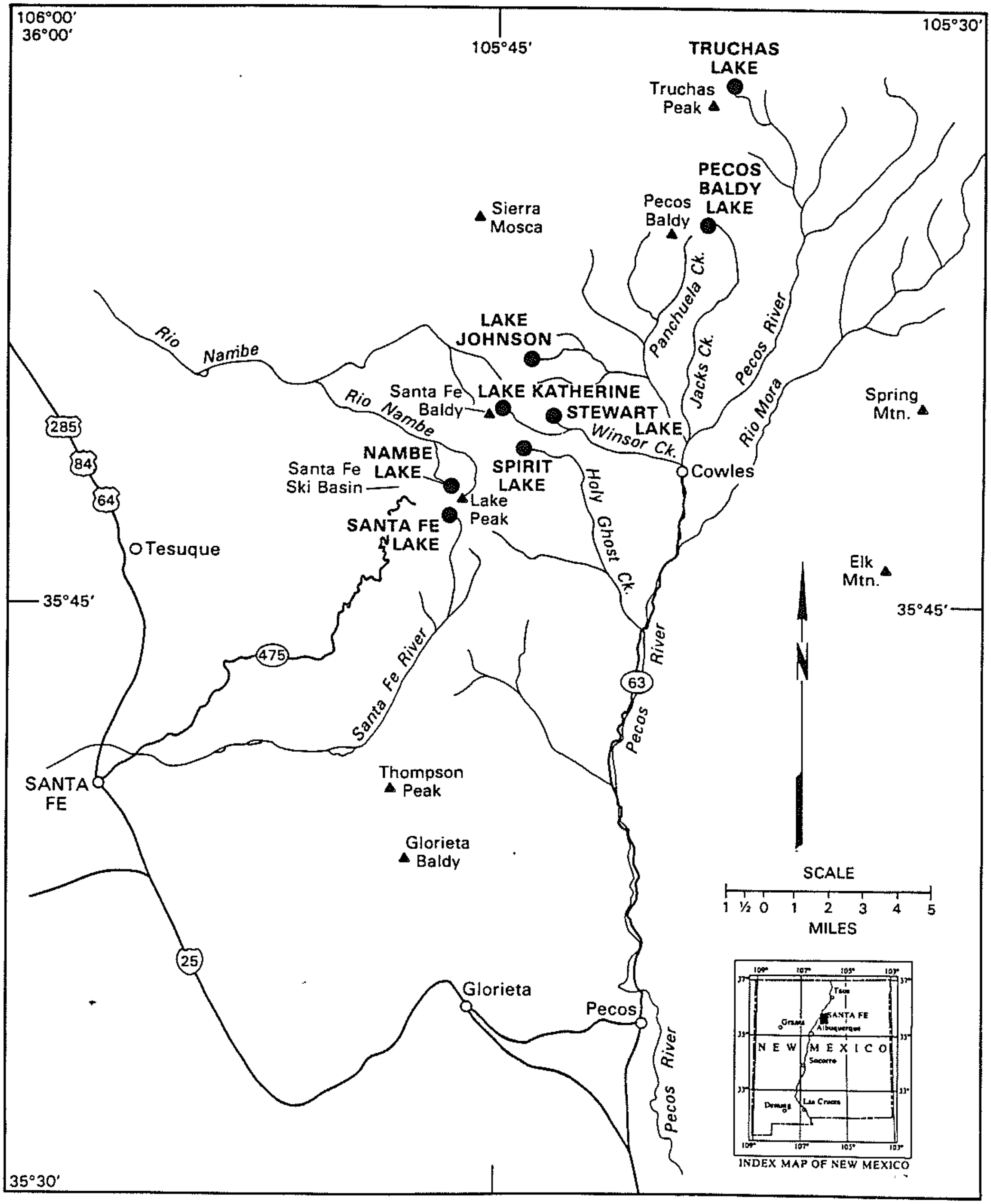


Fig. 2. Pecos Wilderness Study Area

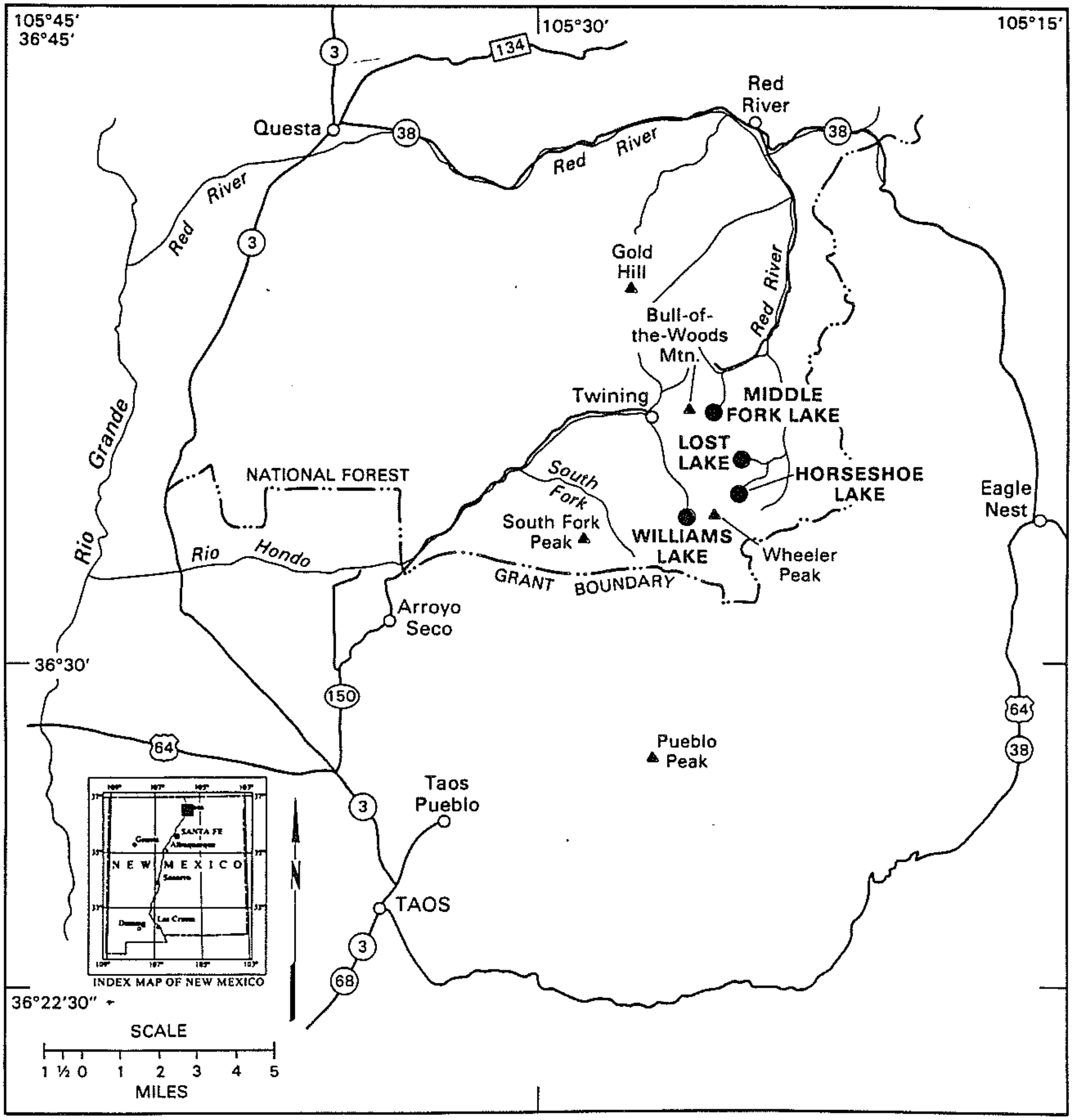


Fig. 3. Wheeler Peak Wilderness Study Area

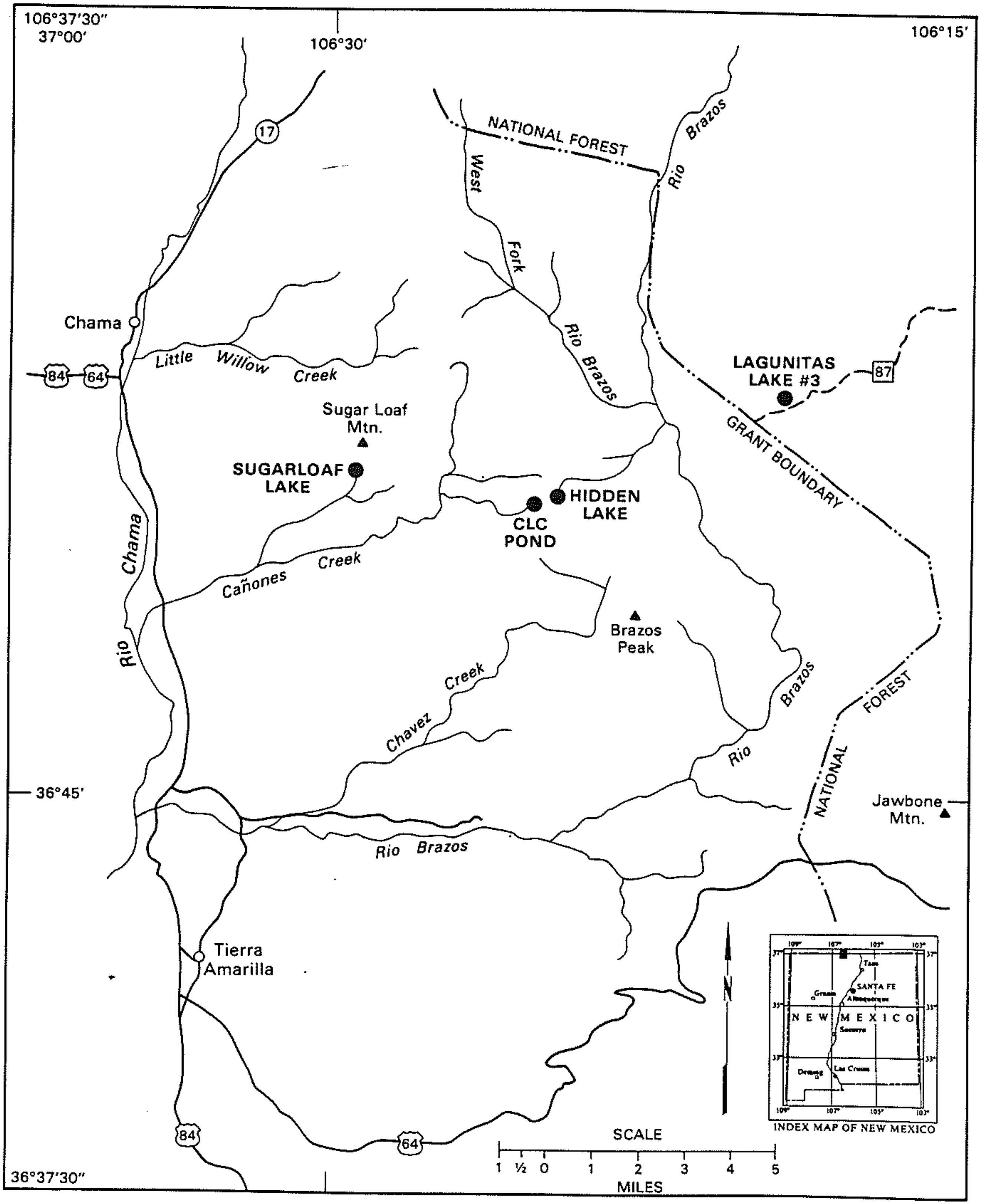


Fig. 4. Brazos Uplift Study Area

TABLE 2

Sampling Dates for Lakes

Lake	Sampling Dates		
Brazos Uplift			
CLC Pond		06-21-87	
Hidden		06-20-87	07-05-88
Lagunitas #3		06-23-87	
Sugarloaf		06-22-87	07-05-88
Pecos Wilderness Area			
Johnson		07-08-87	
Katherine	08-19-86	07-07-87	
Nambe	07-26-86		
Pecos Baldy	08-17-86	07-11-87	
Santa Fe	05-25-86	07-01-87	02-11-88
		08-11-87	03-17-88
		09-03-87	04-09-88
		10-16-87	05-12-88
		11-12-87	05-27-88
		12-16-87	06-14-88
Spirit	06-04-86	07-07-87	06-21-88
Stewart	06-02-86	07-09-87	06-21-88
	08-19-86		
Truchas (Upper)			06-25-88
Truchas (Lower)		07-10-87	06-25-88
Wheeler Peak Wilderness Area			
Horseshoe	07-17-86	07-18-87	
Lost	07-18-86	07-19-87	
Middle Fork	07-15-86	10-08-87	
Williams	07-19-86	07-20-87	

at 10 m intervals along ropes stretched across the smaller lakes. On the larger lakes, positions on the lake were triangulated, depth soundings were obtained, and subsequently transferred to maps. Depth contours were later developed from these soundings for estimating lake volumes.

Surface water samples were obtained for determination of pH, alkalinity, major and trace metals, sulfate, nitrate and chloride ions, and dissolved and total organic carbon. In addition, Secchi disk transparency and depth profiles of temperature, dissolved oxygen, and conductivity were recorded. Water samples from the surface, mid-depth, and bottom were collected for total and calcium hardness, total dissolved solids, chlorophyll *a*, and planktonic diatom analysis. Zooplankton were sampled at each lake by vertically towing a plankton net through the water column at the deepest part of the lake. Samples of the benthic macroinvertebrates (> 0.5 mm) were also collected. Cores of the bottom sediment were obtained and sectioned for chronological analysis of changes in diatom species assemblages and trace metal concentrations. Sections of the Santa Fe and Truchas cores were radiodated to establish an approximate date for the deposition of the different sediment layers. During the year-long sampling of Santa Fe Lake, water samples, profiles, and zooplankton samples were obtained monthly. Benthos samples were collected quarterly.

Where possible, snow was obtained from remnant drifts and subjected to pH and ion analysis. More intensive precipitation sampling was conducted at Santa Fe Lake. During the warmer months, a polyethylene funnel and collection bottle were set out near the lake to collect bulk precipitation. During the colder months, sufficient snow to fill two large plastic trash bags was collected each month. The snow was returned to the laboratory, allowed to melt, and prepared for sulfur isotope analysis. In addition, surface snow samples were collected for chemical analysis by scraping the top 5 cm into polyethylene bottles. The isotope analysis was conducted at the Laboratory for Isotope Geochemistry by Dr. Austin Long of the University of Arizona in Tucson. Once the snowpack had accumulated to a depth of 61 cm (it eventually reached 214 cm), trenches were dug in the snow and samples were obtained at selected depth intervals for pH and ion analysis for the purpose of monitoring changes throughout the winter and when snowmelt occurred in the spring.

Water Sampling and Analysis

Surface areas of the lakes and watersheds were calculated using planimetric techniques (Lind 1979) on enlargements of USGS 7 1/2 minutes topographic maps. Lake volumes were calculated from surface areas of the depth contours multiplied by the depth interval between contours and then summed.

The pH of surface water grab samples was determined in the field using one of several available portable pH meters. The meters were recalibrated with two buffers at each lake. Alkalinity was measured in the field by potentiometric titration with a microliter pipette according to the Gran procedure (Stumm and Morgan 1981). U.S. Environmental Protection Agency alkalinity standards were run with each titration for quality assurance purposes.

Grab samples of surface water were collected for analysis of cations, anions, major and trace metals, total and calcium hardness, chlorophyll a, dissolved (DOC) and total organic carbon (TOC), and total dissolved solids. Water samples were filtered through 0.45 micron membrane filters in the field using an Antlia filter pump prior to analysis. All samples were stored in acid-rinsed polyethylene bottles except the DOC and TOC samples which were stored in glass bottles. Water samples destined for major and trace metal analysis were preserved with several drops of redistilled concentrated HNO_3. Metals were analyzed on an inductively coupled plasma spectrometer (Perkin-Elmer Model 6500).

Total and calcium hardness were determined by titration with ethylene diamine tetraacetic acid in the presence of Eriochrome Black T and murexide indicators respectively (Lind 1979). Chloride, nitrate, and sulfate were analyzed by ion chromatography using a Dionex Model 2000 i/SP.

Chlorophyll _a_ was quantified following 90% alkaline acetone extraction of 0.45 micron membrane filters using the monochromatic method on a Bausch and Lomb Spectronic 20 Spectrophotometer (Lind 1979). All results were corrected for the presence of phaeophytin _a_, a degradation product of chlorophyll. Total dissolved solids were determined gravimetrically by evaporating known volumes of membrane-filtered sample (0.45 micron) to constant weight at 103-105°C (Lind 1979).

Organic carbon analysis was performed on water samples using the Environmental Protection Agency Combustion Method 415.1 (EPA 1979). The instrument used was an O.I. Corporation Model 524C, Organic Carbon Analyzer.

Depth profiles of temperature, specific conductance, and dissolved oxygen were established at least once for each lake and on a monthly basis for Santa Fe Lake. Temperature and conductivity were measured with a Yellow Springs Instrument Company Model 33 salinity-conductivity-temperature meter. Conductivity readings were converted to specific conductance at 25°C. Water samples for dissolved oxygen determination were collected at each depth with a 2.2 l Kemmerer water sampler. The water was brought to the surface and placed in glass B.O.D. bottles. The samples were then fixed and analyzed using the procedures of the Winkler titration (American Public Health Association 1985).

Secchi disk transparency was determined using a 10 cm diameter disk on a calibrated rope. Reported Secchi depths are the arithmetic mean of the depths where the disk was observed to disappear and to reappear.

Biological Sampling and Analysis

Planktonic diatom samples were collected from a depth of 0.5 m in all lakes by submerging sample bottles. In lakes whose depths exceeded 2 m, samples from the mid-depth and bottom were also collected using a Kemmerer water sampler on a calibrated line. All samples were preserved in the field with Lugols iodine. Upon return to the laboratory, the samples were concentrated by sedimentation to 10 ml. Known volumes of the sample concentrate were evaporated onto microscope coverslips using a hot plate. The coverslips were then combusted at 550°C for 1 hour to oxidize any organic matter present in the sample. The coverslips were cooled and permanently mounted onto slides. The slides were examined by light and phase contrast microscopy at 1000x for species composition and abundance.

Zooplankton samples were collected by vertical tows with a No. 12 (130 micron) 25 cm diameter plankton net. The samples were narcotized using club soda and then preserved in 10% buffered formalin. Upon return to the lab, zooplankton were identified and enumerated using dissecting and compound light microscopes.

Benthic organisms were sampled using an Ekman dredge (232 cm^2). Each sample consisted of a composite of three grabs. Organisms were separated from the finer substrates by washing the fines through a 0.5 mm mesh screen. The organisms were placed in Whirl-Pak bags and preserved in 70% ethanol. Identification was performed in the laboratory using a Bausch and Lomb Stereozoom 7 dissecting microscope and appropriate invertebrate taxonomic keys. The total number of organisms collected was expanded from the three grabs to numbers of organisms/m^2.

Sediment Coring

In the shallower lakes, sediment cores were obtained from the deepest part of each lake using a 4.5 cm I.D. Plexiglas core tube strapped onto an aluminum extension pole. In the deeper lakes, a modified Brinkhurst core sampler was utilized (Brinkhurst et al. 1969). The modification consisted of removing the plunger and triggering mechanism which inhibited penetration of the compact sediments. Once the corer penetrated the sediments, a lead doughnut on a second line was lowered down the corer line. The doughnut was subsequently raised and lowered in pile-driver fashion to obtain a longer core. The coring device was then brought to the surface, capped, and transported to shore. The cores were extruded from the bottom of the core tube using a plunger. As the cores were extruded, they were sliced into sections approximately 1 cm thick. Each section was placed in a Whirl-Pak bag, which was frozen upon return to the laboratory. Total lengths of the cores and the abbreviations used in their descriptions are shown in table 3.

In the laboratory, at least five sections of the core, at evenly spaced intervals (top, top middle, middle, bottom middle, and bottom), were selected for analysis. Samples were placed in glass freeze-dry flasks and frozen in an ethanol-bath shell-freezer (Labconco) at 60°C. The frozen samples were then transferred to a lypholyzer (Labconco Model 5) and freeze-dried at -50°C under a vacuum of 25 microtorr.

One gram of the freeze-dried sample was placed in a Teflon beaker with 3 ml of deionized water, 6 ml of aqua regia prepared from redistilled acids, and 6 ml redistilled hydrofluoric acid. The solution was heated to near dryness to prevent volatilization of elements such as Pb. Five ml of redistilled HNO_3 and 5 ml of 30% H_2O_2 were added and the mixture was heated to near dryness. The sample was then filtered, rinsed with known amounts of 10% redistilled

TABLE 3

Lake Sampled, Abbreviation, and Sediment Core Length

Lake Sampled	Abbreviation	Length of Core (cm)
CLC Pond	CLC	8
Hidden	HL	8
Horseshoe	H	34
Johnson	J	14
Katherine	K	20
Lagunitas-3	LAG	32
Lost	L	15
Middle Fork	MF	39
Nambe	N	30
Pecos Baldy	PB	22
Santa Fe	SF	18
Spirit	S	33
Stewart	ST	14
Sugarloaf	SGL	8
Truchas	T	21
Williams	W	30

HNO_3, and brought to a volume of 100 ml with a solution of 10% redistilled HNO_3.

Radiodating: Determination of Pb-210 and Cs-137

Each individual section from the sediment core was mixed well to ensure homogeneity and transferred to a 5 cm diameter glass petri dish. A 5 g sample was used from each core section, if available. If less than 5 g were available, adjacent sections were combined. The dishes were sealed with tape, and, if Pb-210 analysis was desired, allowed to stand for a minimum of two weeks for Rn-222 and, hence, Pb-214 ingrowth. Procedures for Pb-210 followed those of Schery (1980) as adopted by Dehn (1983) and Novo-Gradac (1983).

Activities of the radioisotopes Pb-210, Pb-214, and Cs-137 were obtained by gamma spectrometry, using an N-type, high purity, low background lithium-doped germanium detector. The gamma spectra were obtained using a lead-shielded Ortec Gamma-X spectrometer linked to a 4096-channel pulse-height analyzer. Minimum counting times for Cs-137 and Pb-210 were 4,000 and 16,000 seconds, respectively. The energy range of the spectra in both cases was approximately 0.1500 keV. For low levels, counting times of about 40,000 seconds were found to be sufficient.

The efficiency of the detector at a number of different energies was determined by counting several sediment samples impregnated with known quantities of nine radionuclides (Reference Standard QCY,44, Amersham Corp., Amersham, England) including Cs-137. A separate Pb-210, 1μCi standard was obtained from Isotope Products Laboratories and added to the impregnated samples. As the efficiencies were found to be largely unaffected by the mean grain size of the sediment matrix of the standards, values obtained from a mixture of equal quantities of medium sand and silty clay were used. Efficiencies at other energies were found by interpolation, using programs provided for this purpose by Nuclear Data Corporation (1980).

The areas of the Pb-210 peak at 46.5 keV were calculated using a peak area extraction program provided by Nuclear Data Corporation (1980). The areas of selected peaks were checked visually to verify the accuracy of the program and the resolution of the peaks in the spectrum.

Activities of each isotope (in pCi/g) were calculated from peak areas, sample weights, and branching ratios, using previously determined efficiencies at these energies. The branching ratios for measured Pb-210, Pb-214, and Cs-137 decays were taken to be 4.05%, 37.2%, and 84.6%, respectively (Erdmann and Soyka 1979). Where necessary, corrections were made for the presence of peaks at the same locations in background spectra.

Both Pb-210 and Pb-214 peaks were clearly resolved by gamma spectrometry, with full peak widths at half the maximum peak height above background (FWHM) of approximately 1.1 and 1.3 keV, respectively. Peak shapes were consistently Gaussian, and centroid energies were in good agreement with one another and with published values (National Council on Radiation Protection 1978), which indicates that significant interferences were absent.

Sediment Particle Size Analysis

Sediment core samples were removed for particle size analysis and X-ray mineralogy from near the top and bottom of each core. Particle size analysis was performed by first oven-drying each sample at 70°C. Large pieces of organic matter (sticks, pine needles, etc.) were removed with forceps. Smaller pieces tended to float when the samples were rewetted and, therefore, were removed by skimming. Several samples (S16, S30, MF10-11, MF31-32, N6-7, H28-29, LAG1, K16, K6, ST11, ST5, ST2, SGL8, SGL2, and CLC2) contained such large quantities of organic matter that it was necessary to oxidize the small pieces with 30% H_2O_2 using the method of Janitzky (1986). These samples were placed in 250 ml beakers. Three 4-5 ml aliquots of 30% H_2O_2 were added to each sample at 5 minutes intervals. After about one-half hour, the initial foaming subsided and the beakers were covered with watchglasses and heated for 1 hour at 70°C on a hot plate. During this time, 4-5 ml aliquots of 30% H_2O_2 were added to each sample every 10 minutes. The samples were then allowed to cool. The sediment was separated from the solution by alternately centrifuging, removing the supernatant, rinsing with distilled water and then centrifuging again. The samples which were not treated with H_2O_2 contained organic matter in minor amounts and this material was removed by mixing each sample with distilled water and floating off the organic matter. These samples were then washed twice with distilled water and centrifuged to remove any ions that might cause flocculation of the clay fractions.

The wet samples were prepared for particle size analysis by drying them overnight in a 70°C oven. Samples were removed from the oven and placed in a desiccator to cool. The samples were weighed to the nearest mg in tared containers and transferred to 1000 ml beakers containing 200 ml of distilled water. Three drops of NH_4OH were added to each beaker to prevent flocculation. The samples were then left for 12-72 hours to allow the clumps of sediment to slake. The samples were placed in an ultrasonic agitator for 0.5-3 hours to further disaggregate clumps followed by wet sieving using a 230 mesh sieve (0.063 mm) to remove particles larger than silt size. The sand grains were removed from the sieve and weighed. The sediment-water mixture was centrifuged at 12,000 rpm for 10 minutes, and the supernatant discarded. The sediment was washed into a 1000 ml beaker and distilled water was added to bring the total content of each beaker to 500 ml. The beakers were vigorously stirred and left for one-half hour to allow the silt-sized particles to settle. Twenty ml of the resulting clay and water solution were pipetted off the surface, dried, and the clay material was weighed. Since this clay represented only 20/500 or 1/25 of the total clay in the sample, the weight of the clay portion was multiplied by 25 to obtain the total weight of the clay sample. The weight of the silt was then calculated by subtracting the weights of the sand and clay from the total weight of the sample.

X-ray Diffraction Analysis

A Rigaku Model DMAX IIA X-ray diffractometer (XRD) using Cu kα radiation was used to identify the minerals present in the lake sediments. Randomly oriented powder mounts of each sample were run from 20° to 60° 2θ. A computer assisted mineral search was performed to aid interpretation of the resulting diffractograms. Although mica was clearly present in some of the samples, the computer failed to identify it. This was probably due to the platy mica grains taking on a preferred orientation in the supposedly randomly oriented powder mount. This would cause only a few of the mica peaks to be recorded by the XRD. In order to avoid this problem, the diffractograms were also examined by checking for diagnostic peaks listed in the American Society for Testing Materials files for minerals likely to be present in the sediments but not identified in the computer assisted search.

A semi-quantitative analysis of the clay minerals present in the sediments was also performed (Austin 1987). This involved mixing the sediments in distilled water to form a slurry and then allowing the silt and sand-sized fractions to settle for 15 minutes. After settling, some of the resulting clay-water mixture at the surface was removed with a pipette, placed on a petrographic slide, and allowed to dry which resulted in an oriented mount. Each sample was run in the XRD at 2° 2θ per minute under three different conditions: (1) from 2° to 35° 2θ with no treatment, (2) from 2° to

15° 2θ after 24 hour in an ethylene glycol atmosphere, and (3) from 2° to 15° 2θ after heating the slide at 375°C for one-half hour. If both chlorite and kaolinite were found to be present, a slow "no treatment" run from 24° to 26° 2θ at 0.5° 2θ per minute was also necessary.

The purpose of these various treatments was to differentiate between mixed layer clay minerals and clay minerals with expanding and non-expanding lattices. The proportions of the various clay minerals present were then calculated from the relative peak intensities using the following equations developed by George Austin of the New Mexico Bureau of Mines and Mineral Resources:

$$\text{Illite} = \frac{I(1G)}{T} \times 10$$

$$\text{Montmorillonite} = \frac{\frac{M(1)}{4}}{7} \times 10$$

$$\text{Chlorite} = \frac{C(3)}{I(2)} \times \frac{I(1G)}{T} \times 10$$

$$\text{Mixed Layer Illite/Smectite} = (1H) - \frac{\left[I(1G) + \frac{M(1)}{4}\right]}{T} \times 10$$

$$\text{Kaolinite} = \frac{K(1)}{T} \times 10$$

or, if chlorite is present,

$$\text{Kaolinite} = \frac{K(2)}{2C(4)} \times \frac{C(3)}{I(2)} \times \frac{I(1G)}{T} \times 10$$

where T = total counts:

$$T = I(1H) + K(1)$$

or, if chlorite is present,

$$T = K(1H) + \frac{C(3) \times I(G)}{I(2)} + \frac{K(2) \times C(3) \times I(1G)}{2C(4) \times I(2)}$$

where:

I(1H) = intensity* of peak at 8.8° 2θ on the heated run

I(1G) = intensity of peak at 8.81° 2θ on the glycol run

M(1) = intensity of peak at 5.2° 2θ on the glycol run

K(1) = intensity of peak at 12.4° 2θ (first order kaolinite peak) on the initial no treatment run

K(2) = intensity of peak at 25.1° 2θ (second order kaolinite peak) on the slow no treatment run

I(2) = intensity of peak at 17.8° 2θ on the initial no treatment run

C(3) = intensity of peak at 18.4° to 18.9° 2θ (third order chlorite peak) on the initial no treatment run

C(4) = intensity of peak at 25.1° 2θ on the slow no treatment run

* = peak height above background

Sediment Diatom Preparation

Diatoms were examined from sections of selected sediment cores. From each section, 0.3 - 0.5 g wet weight of sediment were removed and placed in a one l beaker. The sediments were digested using the methodology of Van Der Werff (1955). Basically this consisted of overnight digestion in 30% H_2O_2 followed by the addition of potassium dichromate. After repeated rinsing and centrifugation, the sample concentrates were air-dried on microscope coverslips and then mounted onto microscope slides using Hyrax mounting media (refractive index = 1.65). Randomly chosen fields were examined at 1000x for species composition until 500 cells had been identified.

Metal Analysis

The metals Al, Cr, Cu, Fe, Ni, Pb, Zn, Mn, V, Ca, Mg, Na, and K were determined on a Perkin-Elmer 6500 Inductively Coupled Plasma Spectrophotometer (ICP). Mercury was determined on an Instrumentation Laboratories Atomic Absorption (AA) Spectrophotometer using a hydride generator. Canadian Certified Reference Material (SL-1, Canadian Atomic Energy Commission), SY3

(Canadian Syenite Standard for Uranium), National Bureau of Standards (NBS) 1645 (River Sediment), and NBS 1646 (Estuarine Standard) were used as standard materials. The results of the analyses of the standards are reported in table 4. Table 5 lists the detection limits for the major and trace metals analyzed on the ICP and AA. Approximately 10% of the samples were run as duplicates as part of the quality control.

Precipitation Analysis

Analytical procedures were verified with EPA standards as controls. Approximately 10% of the samples were run as duplicates; spikes and blanks were also analyzed routinely. The pH values were determined using a glass electrode and pH meter calibrated with two buffers (pH 4 and 7) and two "artificial rain" low ionic strength solutions which were made with dilute HNO_3 at pH's between 3 and 4. The artificial rain samples were then titrated accurately to determine H^+ concentrations for calibration. Snow samples were melted and brought to room temperature before analysis.

Nitrate, chloride, and sulfate were analyzed by ion chromatography using a Wescan 2 ml sample loop, anion column (Wescan 269-101), and conductivity detector (Wescan 213A) coupled with a Beckman Model 110A high performance liquid chromatograph (Buchholz et al. 1982), or a Dionex 2000 i/SP ion chromatograph. Cations were analyzed by atomic absorption (AA) using a Model 857 AA manufactured by Instrumentation Laboratories, Inc., or a Varian Techtron Model 1250 AA.

Sulfur Isotope Analysis

Sulfate was extracted from precipitation by ion exchange using Amberlite CG-400 anion exchange resin. The ion exchange columns were backflushed with 0.3 molar sodium chloride. Sulfate was precipitated as barium sulfate using

TABLE 4

Comparison of Detected and Actual Values for Trace Metals in Standard Reference Materials

Standard	Trace Metal Concentration (ppm)									
	Al	Cr	Cu	Fe	Hg	Ni	Mn	Pb	V	Zn
SY3										
Actual	DNP	12	16	DNP	DNP	11	DNP	80	51	240
Detected		58	18			5		96	31	212
NBS-1646										
Actual	625	76	109	33500	1	46	785	28	24	1720
Detected	246	35	115	27200	1.07	39	768	34	11	1740
NBS-1645										
Actual	DNP	29600	18	11300	.063	32	375	714	94	138
Detected		20600	20	10000	.064	27	365	735	61	115
SL1										
Actual	89000	104	30	67400	.13	45	3460	38	170	223
Detected	86200	78	24	51300	.15	47	3680	47	128	175

SY3 = Canadian Syenite Standard for Uranium
SL1 = Canadian Certified Reference Material
NBS-1645 = National Bureau of Standards River Sediment
NBS-1646 = National Bureau of Standards Estuarine Sediment

DNP = Data Not Provided

TABLE 5

Detection Limits for Major and Trace Metals Analyzed by ICP and AA Spectrophotometry

Element	Detection Limit (ppm)
Al	.045
Ca	.00019
Cr	.0061
Cu	.0054
Fe	.015
Hg	.025
K	42.88
Mg	.00015
Mn	.0014
Na	.069
Ni	.045
Pb	.50
V	.005
Zn	.0018

10% barium chloride.

The barium sulfate samples were treated with dilute HCl to remove traces of carbonate before conversion to SO_2 which is used in the mass spectrometric determination. Sulfur dioxide for mass spectrometric analysis was obtained by heating a mixture of 25 mg $BaSO_4$, 200 mg SiO_2, and 200 mg Cu_2O in a 6 mm O.D. Vycor boat at 1100°C for 15 minutes under vacuum. The SO_2 was separated from H_2O and CO_2 cryogenically and analyzed on a V.G. Micromass 602-D mass spectrometer. Laboratory accuracy and precision is +/- 0.25 per mil and the values are referenced to Cañon Diablo troilite.

Statistical Analysis of Trace Metal Data in Cores

Comparisons of enrichment factors and trace metal concentrations in sediments were made using the paired t-test at the 90% confidence level ($P < 0.1$). Trace metal trends in the cores were treated by linear regression and correlation analysis to determine if increases or decreases in the cores were significant ($P < 0.1$).

RESULTS AND DISCUSSION

Physical Description of Lakes

During the summers of 1986, 1987, and 1988, seventeen lakes were sampled. Most of the lakes were sampled at least twice during two consecutive summers while selected characteristics in others were measured as many as four times. Santa Fe Lake was sampled monthly during 1987-88. All of the lakes are located, with one exception, at altitudes exceeding 3048 m (10,000 ft.); ten were at altitudes exceeding 3353 m (11,000 ft.) (table 6).

All of the lakes occur in natural basins, but depth and volume have been enhanced for many when the outlets were raised by state and federal management

TABLE 6

Physical Characteristics of Lakes

Study Area and Lakes	Altitude (m)	Lake Area (ha.)	Basin Area (ha.)	Basin Area / Lake Area	Maximum Depth (m)	Volume (m^3)
Brazos Uplift						
CLC Pond	3,240	<.3	19.7	<65	0.6	ND
Hidden	3,304	3.8	23.5	6.2	6.0	110,999
Lagunitas #3	3,155	0.4	24.8	62	3.0	3,726
Sugarloaf	3,008	2.4	197	82	5.0	41,822
Pecos Wilderness Area						
Johnson	3,383	0.9	74.6	83	7.0	16,642
Katherine	3,579	4.6	40.6	8.8	24.5	630,401
Nambe	3,463	0.9	43.3	48	1.1	3,874
Pecos Baldy	3,487	2.9	64.1	22	4.	47,040
Santa Fe	3,530	1.9	15.9	8.4	7.0	58,327
Spirit	3,295	1.2	17.8	15	4.0	24,957
Stewart	3,119	1.3	170	131	10.2	78,192
Truchas (Lower)	3,618	1.0	32.5	33	3.5	15,649
Wheeler Peak Wilderness Area						
Horseshoe	3,645	2.6	75.2	29	3.0	43,546
Lost	3,504	3.4	69.9	21	7.5	151,149
Middle Fork	3,306	3.3	59.7	18	3.9	57,832
Williams	3,365	2.5	464	186	2.1	31,900

ND = Not Determined

agency personnel. Motorized access is restricted to many of the lakes by virtue of their wilderness designation. Four wheel drive vehicles, motorcycles, and all terrain vehicles have access to Middle Fork Lake. Motor vehicles can also have access to the lakes in the Brazos Uplift Study Area, but vehicle travel is restricted due to private ownership. The most obvious signs of human disturbance at the lakes are the high number of fire pits around the shorelines, and debris left behind by fishermen and campers.

The basin walls around the lakes were usually very steep and composed of thin rocky soils, bare outcrops, and talus. Vegetation in the basins varied widely from extensive coverage by spruce-fir (e.g., Spirit Lake) forest to low shrubs and grasses above timberline (e.g., Horseshoe Lake).

The lakes are small in size with surface areas less than five hectares (table 6). The lakes are shallow, typically having maximum depths of less than seven meters although Lake Katherine is considerably deeper. Estimated lake volumes ranged from 3,726 m^3 to 630,401 m^3. Watershed surface area to lake surface area ratios ranged from six to 186. Five of the lakes had ratios less than 20, a value associated with many acidified lakes in the eastern United States (Landers et al. 1988).

Lake water was colorless with no indication of any staining by dissolved organic acids. Total organic carbon values were usually less than 5 mg/l (table 7). Except for slight differences caused by experimental error, dissolved organic and total organic carbon values were identical. The Secchi disk was visible on the bottom of the more shallow lakes and transparency values often exceeded 4 m in the deeper lakes (table 7). These values are indicative of the low concentrations of suspended particles and dissolved organics. Chlorophyll a values, a measure of algal cell density, were generally less than 10 μg/l and often below the detection limits of the

TABLE 7

Secchi Disk Transparency, Total Organic Carbon (TOC) and Chlorophyll a (chl a) for High Altitude Lakes in New Mexico. Chlorophyll a has been corrected for phaeopigments. Hyphenated values indicate the range for two or more sampling times.

Study Area and Lake	Secchi Disk (m)	TOC (mg/l)	Chl a (μg/l)
Brazos Uplift			
CLC Pond	VTB	3.4	5.0
Hidden	2.5	*	1.9-6.1
Lagunitas #3	1.3	3.6	6.2
Sugarloaf	1.0	6.6-6.7	3.9-9.7
Pecos Wilderness Area			
Johnson	4.5	3.1	3.5
Katherine	5.0-6.0	0-1.3	3.5-184
Nambe	VTB	1.1	59
Pecos Baldy	3.2	0-2.0	0-5.2
Santa Fe	3.0-4.0	0-4.5	0-137
Spirit	VTB	1.2-2.8	0-5.8
Stewart	4.2	0.9-2.1	0-7.2
Truchas (Lower)	2.7	1.9-5.1	0
Truchas (Upper)	VTB	0	0
Wheeler Peak Wilderness Area			
Horseshoe	VTB	1.1-1.3	0-15
Lost	4.7-4.9	0.8-2.1	0-28
Middle Fork	VTB	0-7.5	0-7.2
Williams	VTB	0-2.2	0-4.8

VTB = Visible to Bottom
* Sample broken in transit

analytical procedure (1.9 μg/l).

Chemical Analysis of Lake Water and Precipitation

An examination of table 8 indicates that the lakes generally have circumneutral to slightly alkaline pH's and are dilute, softwater lakes of low to moderate alkalinity. Water chemistry data for the lakes are summarized in Appendix M. Ion balances are generally within 10%. The two Truchas lakes and Santa Fe Lake are considerably more acidic and have lower alkalinity than the majority. The dilute nature of the water is easily seen in the low total dissolved solids (TDS) concentrations and the low conductivity values. The lakes consistently exhibit higher hardness than alkalinity indicating the presence of anions other than those associated with the carbonate-bicarbonate buffering system. Calcium is the major divalent cation in these systems and sulfate is the major anion. Differences between total hardness and calcium hardness are due mostly to the presence of magnesium ions. Further inspection of the chemical data (table 8) reveals discernible differences between the lakes of the different study areas. With the exception of Pecos Baldy Lake, lakes in the Pecos Wilderness tend to be more acidic and have lower values for alkalinity, total and calcium hardness, TDS, and conductivity. Hidden Lake, in the Brazos Uplift group, is the only other lake that has values approaching those of the Pecos group.

Generally, most of the lakes had cool, well oxygenated water, with no sharp thermoclines (Appendix A). A thermocline occurred both years in Lake Katherine along with low dissolved oxygen concentrations near the bottom. Lake Johnson, which is 7 m deep, was thermally stratified in July 1987. Sugarloaf (5 m deep) and Hidden (6 m deep) Lakes were stratified in May 1987 and showed near anoxic conditions above the bottom. A sharp decrease in epilimnetic dissolved oxygen concentration from 8.2 mg/l at the surface to 2.8

TABLE 8

Chemical Limnology of the Lakes by Study Area. Hyphenated values indicate the range of values for samples taken on two or more occasions.

Study Area and Lake	pH	ANC mg/l	Hardness mg/l	Ca Hard. mg/l	TDS mg/l	Specific Conductance 25°C µS/cm
Brazos Uplift						
CLC Pond	7.5	25	29	19	18	48
Hidden	6.4-6.9	8-13	16-23	11-14	23-37	48
Lagunitas #3	8.3	41	45	35	36	94
Sugarloaf	6.9-8.5	19-24	28-34	17-21	29-48	62
Pecos Wilderness Area						
Johnson	6.4	8	13	8	13	34
Katherine	6.9-7.2	6-7	8-10	8	42	25-27
Nambe	6.8	10	ND	ND	42	34
Pecos Baldy	7.7-8.3	49-56	49-56	48	43-103	105
Santa Fe	5.6-7.1	5-10	9-26	6-27	18-44	16-38
Spirit	6.7-7.4	10-12	12-17	6-10	24-61	28-33
Stewart	6.5-6.9	7-10	9-12	8	34-46	26-37
Truchas (Lower)	5.4-5.5	0.4-1	3-7	2-3	6-28	4-16
Truchas (Upper)	5.1	0.3	2	2	29	7
Wheeler Peak Wilderness Area						
Horseshoe	7.8-8.4	41-48	63-65	58	80-95	134-136
Lost	7.7-8.4	29-42	43-45	39	53-70	94-95
Middle Fork	7.7-8.6	51-58	69	50	71-74	104-121
Williams	7.5-7.6	22-31	44-48	26	46-73	95

ANC = Acid Neutralizing Capacity
ND = Not Determined

mg/l at 2 m characterized Stewart Lake (10 m deep) in May 1986. Santa Fe Lake (7 m deep), which was sampled for one year, exhibited a typical dimictic pattern for temperature and dissolved oxygen concentration (Appendix B).

Within a given study area, lake chemical properties tended to be very similar. Major differences between study areas and between lakes within a study area can be attributed to differences in the surface geology and mineralogy of the watersheds. These differences will be discussed in more detail later in this report.

Sulfur Isotope Analysis. Isotopic analysis of the stable isotope S-34 was performed on sulfate extracted from samples of lake water and precipitation. Precipitation samples were collected from the basins of Santa Fe Lake in the Pecos Wilderness and Hidden Lake in the Brazos Uplift. Additional samples were collected near Chama, New Mexico, which is adjacent to the Brazos Area. The results are shown in table 9. Concentrations of the S-34 isotope found in precipitation and lake waters from the Santa Fe Basin were virtually the same (within experimental error). Previous data on S-34 concentrations in precipitation of central New Mexico (Popp et al. 1986) were similar to the ranges observed in this study (table 9). The similarity in S-34 abundances indicates that the regional source(s) of sulfur, which ends up in precipitation, is/are quite homogeneous. In addition, the similarity in S-34 abundances over such a large region suggests a distant source that allows time for the isotope to become well mixed, or alternatively, a large regional contribution from entrained soil material. Schlesinger and Peterjohn (1988) report a median S-34/S-32 ratio of +6.2 ^{o}/oo for soils collected in the southwestern USA, including Arizona, Colorado, California, New Mexico, Nevada, and Utah. Unfortunately, they did not report the data by individual state. Sulfide ores (a potential large regional source of atmospheric sulfate) range

TABLE 9

Sulfur Isotope Analysis of Sulfate in Lake Water, Rain, and Snow Samples, and Local and Regional Sulfide Ores, Coals, and Soils

Date	Sample	S-34 (^{o}/oo)
1985-86	Chama Snow	+4.20
06-20-87	Hidden Lake Snow	+3.65
07-01-87	Santa Fe Lake Snow	+3.43 (old)
08-11-87	Santa Fe Lake	+3.32
09-03-87	Santa Fe Lake	+3.32
12-16-87	Santa Fe Lake Snow	+3.20 (fresh)
1984-87	Socorro Rain* (26 samples)	+3.0 ± 1.5
1984-87	Langmuir Laboratory Rain* (12 samples)	+3.3 ± 1.2
	Coal (Four Corners)*	-16.7 to +8.3
	Sulfide Ores (Long1988)	-5 to +5
	Evaporites (Local)**	+20
	Soils (Southewestern USA)***	+6.2

---

* Values reported by Popp et al. (1986) were 2.9 ± 1.0 from 11 Socorro samples and 3.9 ± 1.2 for six Langmuir samples collected between 1984 and 1986

** Schleslinger and Peterjohn (1988)

*** Hoefs (1980)

from -5 ^{o}/oo to +15 ^{o}/oo (Nielson 1974) with ores in Arizona in the -5 to +5 ^{o}/oo range (Long 1988) (table 9). Generally, evaporite deposits exhibit ratios from +9 to +27 ^{o}/oo (Hoefs 1980). Clearly, the lack of detailed information regarding sulfur isotope distributions in precipitation, sulfide ores, soils, and coal in the southwestern USA precludes any conclusions regarding source-receptor relationships at this time. Nevertheless, the similarity between S-34/S-32 ratios in Santa Fe snow and lake water samples supports the presumption that the sulfate in the lake is essentially all atmospherically derived. It is not likely that sulfur reducing bacteria in the lake sediments are influencing sulfur isotope ratios in the water because this process would increase S-32 in the sulfides and increase S-34 (more positive) in the water column. The values for S-34/S-32 are lower than regional soil and evaporite values which suggests a chemically reduced S source as a major contributor to the sulfate in precipitation in this region.

Lake Water Chemistry. Most of the lakes were sampled at least twice between 1986 and 1988, Stewart and Spirit were sampled three times, and Santa Fe Lake was sampled 13 times. The sampling period was too short to show clear trends, but the alkalinities of Stewart and Spirit Lakes declined between 1986 and 1988 (table 10). Alkalinity and pH data from the monthly sampling of Santa Fe Lake are shown in figure 5; the January 1988 sample was not obtained due to avalanche danger. Alkalinities and pH values are virtually the same in May of 1986 and 1988. Peaks in alkalinity occurred in September, December, and early May. The peak in early May was followed by an almost 50% drop in alkalinity 15 days later which corresponded to the period of most rapid snow melt. A corresponding drop in pH, which slightly preceded the alkalinity drop, was also observed and is known as "acid shock." This finding differs from results of a study in the mountains of west-central Colorado which

TABLE 10

Alkalinities for Stewart and Spirit Lakes - μeq/L (values from Appendix C)

Date	Stewart Lake	Spirit Lake
06-86	204	247
07-87	187	246
06-88	143	208

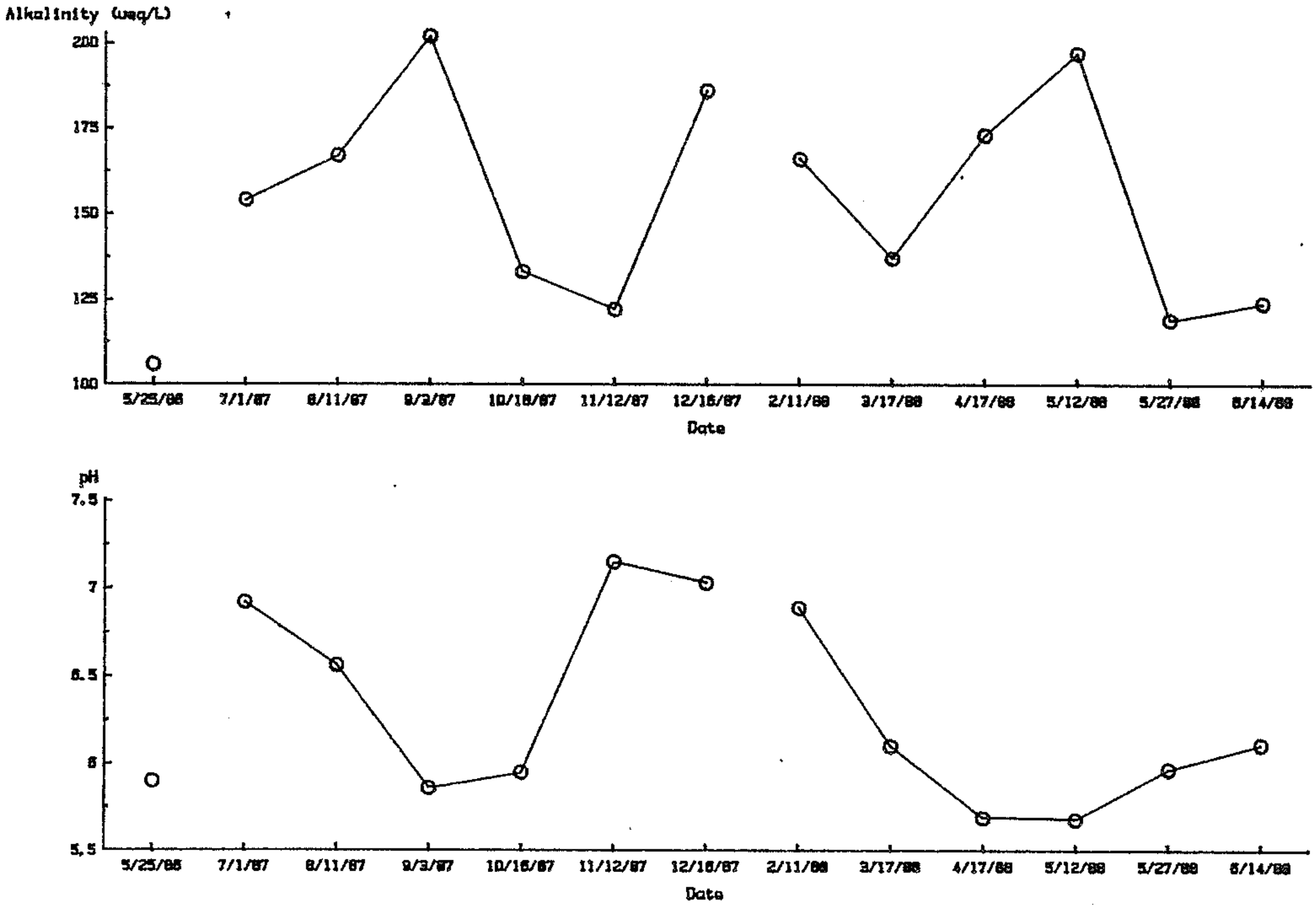


Fig. 5. Temporal Changes of Alkalinity (μeq/l) and pH in Santa Fe Lake. Samples were not obtained during January, 1988, due to avalanche danger.

concluded that an acid pulse did not take place and that the snowpack was alkaline at the time of rapid snow melt (Michaels et al. 1987) Snowpack and precipitation chemistry will be discussed in detail in the following section. Fluctuations in pH and alkalinity also occurred in late summer, but were not associated with any obvious influxes of moisture. The exact causes of this late summer fluctuation are unknown, but may be related to thermal destratification or changes in the ratio of photosynthesis to respiration.

Reliable historical data are not available for comparison of the past and present chemistry of these lakes. However, a U.S. Forest Service study details water chemistries for some lakes and streams in the Pecos Wilderness (Duff and Siverts 1969). Values from the present study are compared with the Forest Service data in table 11. The Forest Service data were obtained using a Hach field test kit; therefore, some of the analyses were subject to considerable error from lack of precision. For instance, one drop in the alkalinity titration equals 100 μeq/l. The value of 100 μeq/l reported for Truchas Lake could range anywhere between 0 and 100. Even though all of the alkalinities appear to have dropped between 1969 and this study, only the decreases at Katherine, Stewart, and Pecos Baldy Lakes are noteworthy based on analytical precision. All the pH values in the present study are lower than those found in 1969 and these differences are probably real, although pH varies greatly (table 11). The hardness values are quite similar for the two studies, but the results are comparable because the hardness titration is quite accurate using the test kits. Little can be said regarding the other data as modern instrumentation has much greater sensitivity and precision than was possible using the test kits available in 1969.

Hardness and alkalinity data show that Ca^{2+} generally dominates Mg^{2+} (table 12). The ratio of alkalinity to calcium plus magnesium is an

TABLE 11

Comparison of Pecos Wilderness Lake Water Chemistry with U.S. Forest Service Data from 1969 (Duff and Siverts 1969). Forest Service data are shown first. All values are in ppm, except alkalinities (μeq/L) and pH.

Lake	Alk	pH	Hardness	Chloride	Sulfate	TDS
Katherine	300/133	7.8/7.1	10/9	3.7/0.3	5/2.1	<10/42
Pecos Baldy	1100/950	8.5/8.0	45/53	2.5/0.3	4/5.2	55/73
Spirit	300/234	8.3/7.0	10/15	2.5/0.5	4/6.5	10/31
Stewart	300/178	7.3/6.7	5/11	2.5/0.3	5/2.8	15/32
Stewart Lake Bog	300/230	6.5/6.0	10/-	2.5/0.2	12/0.7	10/-
Truchas	100/11	6.5/5.4	5/5	1.7/0.2	7/0.9	<5/17

TABLE 12

Calcium, Magnesium, and Alkalinity Concentrations (μeq/l) in Lake Water Samples. If multiple samples were obtained, the data were averaged. Ratio values less than 1.0 indicate the possibility that some loss of buffering capacity has occurred.

Study Area and Lake	Ca^{2+}	Mg^{2+}	$Ca^{2+} + Mg^{2+}$	Alkalinity	$\frac{Alk}{Ca^{2+} + Mg^{2+}}$
<u>Brazos Uplift</u>					
CLC Pond	384	100	484	500	1.03
Hidden	299	72	371	176	0.47
Lagunitas #3	699	142	841	819	0.97
Sugarloaf	399	123	522	483	0.93
<u>Pecos Wilderness Area</u>					
Johnson	100	40	140	162	1.16
Katherine	91	28	119	133	1.12
Nambe	110	25	135	189	1.40
Pecos Baldy	853	93	946	953	1.01
Santa Fe	125	56	181	153	0.85
Spirit	151	80	231	246	1.07
Stewart	123	48	171	195	1.14
Truchas	33	16	49	8	0.16
<u>Wheeler Peak</u>					
Horseshoe	999	114	1113	961	0.86
Lost	627	133	760	713	0.94
Middle Fork	1248	231	1479	1100	0.74
Williams	863	71	934	630	0.68

indication of the extent to which bicarbonate has been replaced by other anions and, hence, an indication of lake acidification (Henriksen 1979; Kramer and Tessier 1982). Most of the ratios (table 12) are close to 1.0 with the exception of Hidden Lake (0.47), Truchas Lake (0.16), and Williams Lake (0.68). These low values are considered indicators of acidification among low alkalinity lakes. Santa Fe Lake was sampled 13 times and the average ratio calculated was 0.85, but the ratios varied from 0.56 (05-25-86) to 1.60 (05-12-88) which illustrates the wide fluctuations that can occur. The ratio of 1.60 for Santa Fe Lake was followed 15 days later by a ratio of 0.68 (05-27-88) which corresponded to the period of rapid snow melt and concomitant declines in lake pH and alkalinity (figure 5).

Precipitation Chemistry. The precipitation samples were collected as snow and the data compiled in Appendix D. Snow samples were collected from snowfields found within the lake drainage basins. Except for the Santa Fe Lake Basin, the snow samples were obtained in May, June, or July, and were thus well-aged. It was anticipated that windblown dust would have had a significant neutralization effect for snow sampled so late in the year, yet many of the samples had pH values < 5.0. Therefore, the snow melt had the potential to exert a profound influence on lake water chemistry.

On each winter visit to Santa Fe Lake, a snow pit was dug and samples were collected at one-foot intervals to monitor temporal changes throughout the winter and especially when snowmelt was anticipated. The vertical distributions of pH, sulfate, and calcium from February to May 1988 are shown in figures 6, 7, and 8. The major snow melt occurred between the April and May sampling dates with some loss occurring between March and April. The lowermost sections of the snow profile, which had the lowest pH values, disappeared before the May 12 sampling date (figure 6). The pH of the lake

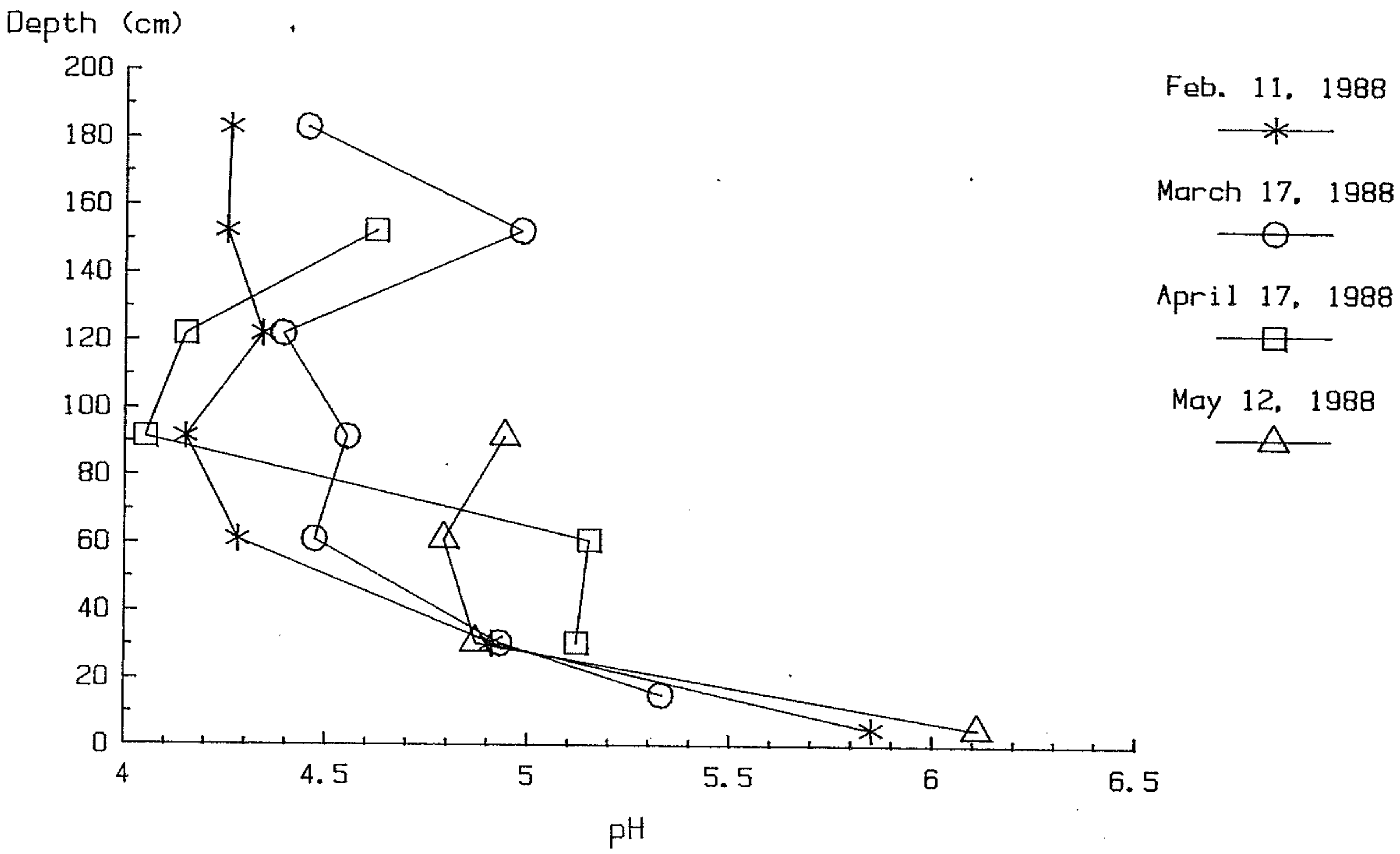


Fig. 6. pH vs. Depth in Snow Pit at Santa Fe Lake

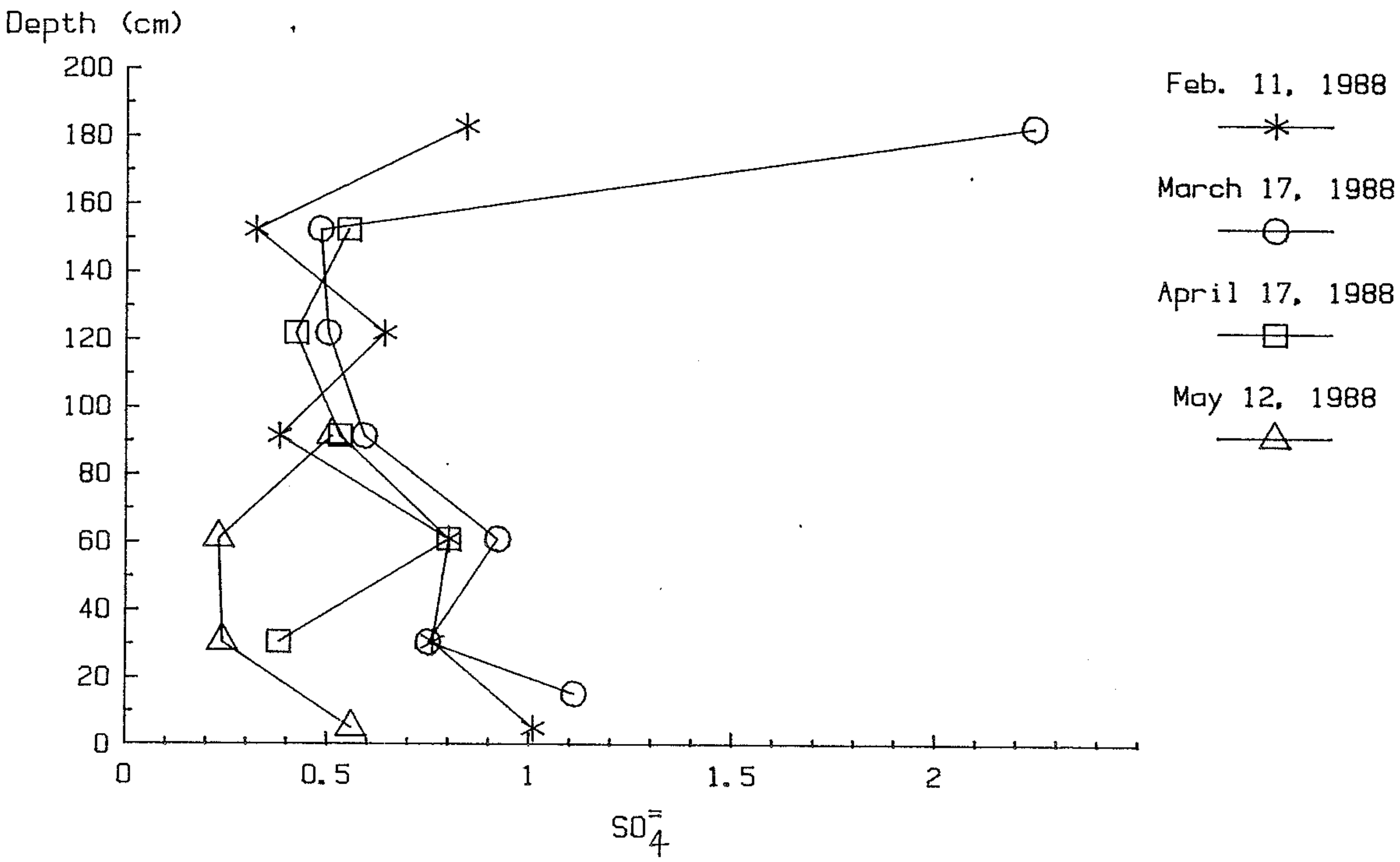


Fig. 7. Sulfate Concentrations (ppm) vs. Depth in Snow Pit at Santa Fe Lake

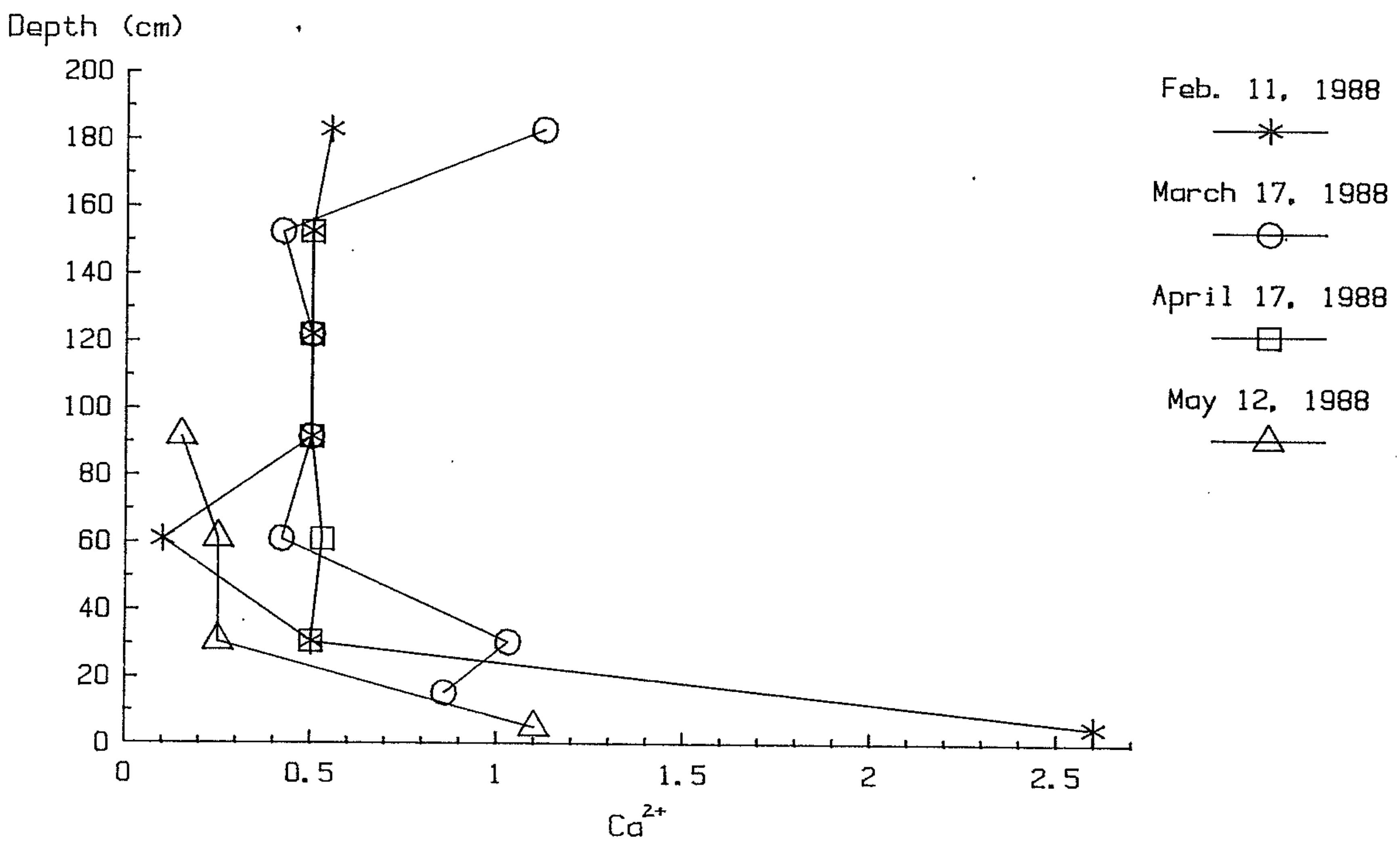


Fig. 8. Calcium Concentrations (ppm) vs. Depth in Snow Pit at Santa Fe Lake

water dropped to its lowest values during this period (figure 5). Sulfate values were highest at the base of the snow in February and March and had become more consistent throughout the snow column by April (figure 7). Calcium levels were generally higher at the top of the snow (figure 8), and nitrate levels were high at both the top and bottom of the snowpack (Appendix D). The low pH values at the bottom of the snow were apparently due to an increase in both sulfate and nitrate. In figure 9, the pH, Ca^{2+}, and SO_4^{2-} values found in the bottom layer of snow are plotted against time during the winter. The pH values remained below 5.0 until most of the snow had melted in late May. The calcium concentration also increased sharply in the late May sample and is probably responsible for the neutralization. In addition, the sulfate and, to a lesser extent, the calcium concentration increased sharply in March followed by a sharp decrease in April. These changes were reflected by increases in both sulfate (1.91 to 2.36) and calcium (1.73 to 2.09) concentrations in the lake water from March to April (Appendix D).

Trace Metals in Sediment Cores

Trends in Cores. Sediment cores were obtained from each of the lakes sampled as shown in table 3. Between four and seven sections from each core were analyzed for a suite of heavy metals (Al, Cr, Cu, Fe, Hg, Mn, Ni, Pb, V, and Zn) to ascertain whether modern sediments reflect increasing anthropogenic inputs to the lake basins from the atmosphere. The relative order of enrichment of these elements in lake sediments is estimated by Galloway et al. (1982) to be Pb > Cu, Zn > Cr > V. Mercury is also enriched in modern sediments as a consequence of man's activities with much of the Hg work performed in Sweden (Renberg 1986). In addition, several studies have shown potential Hg enrichment in surface waters, soils, and fish in New Mexico (Brandvold et al. 1973; Potter et al. 1975; Brandvold 1978; Popp and Laquer

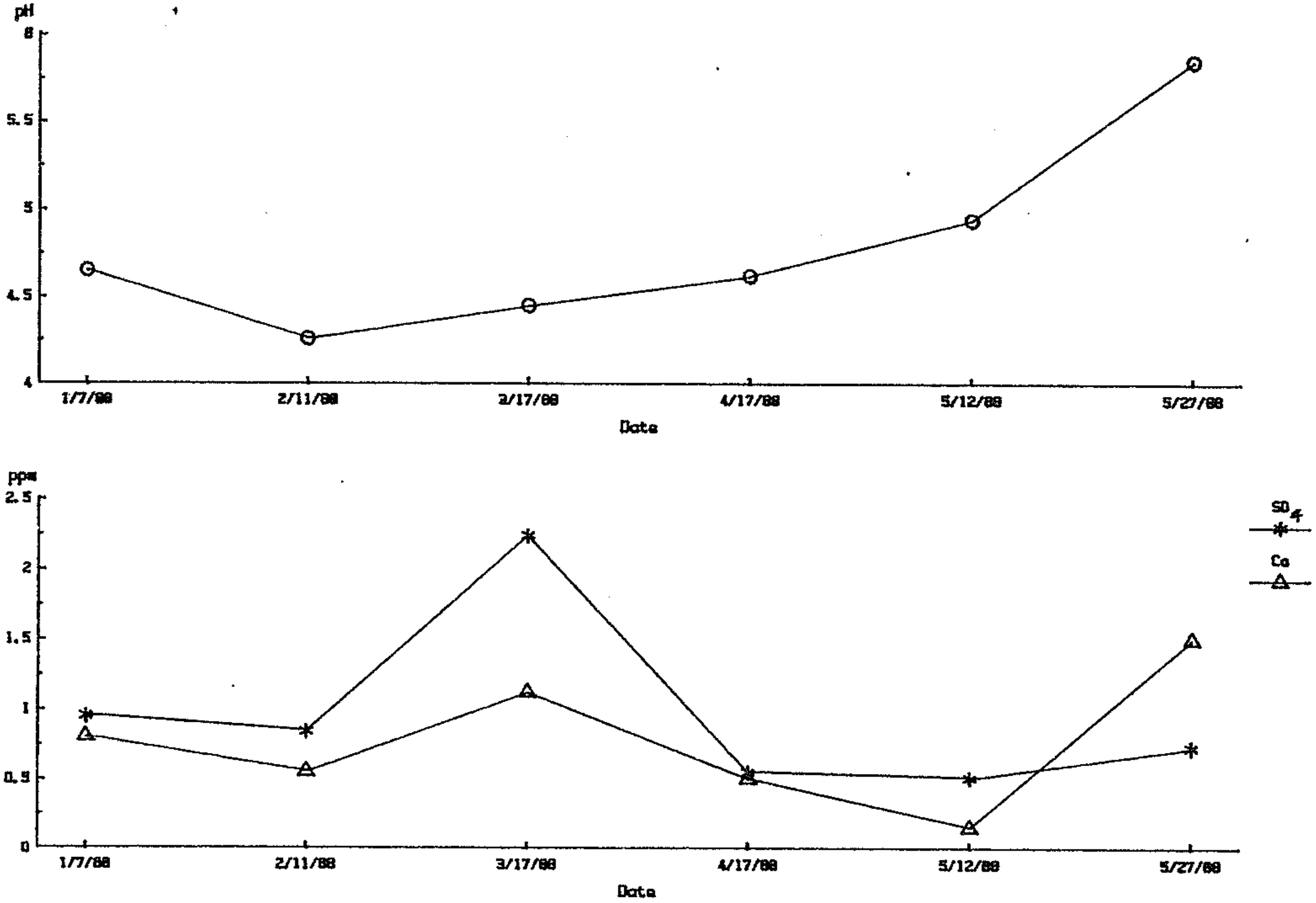


Fig. 9. Temporal Changes of pH, Sulfate and Calcium Concentrations (ppm) in the Bottom Layer of the Snow Pits

1980; Popp et al. 1983; Popp et al. 1986). Nickel was intended to be a "control" metal since no regional emission sources were known. The remaining metals (Al, Fe, Mn) have the potential to be leached from soils and rocks because their solubility increases as the pH of precipitation decreases.

The results of the heavy metal analysis in the core sections are shown in Appendix E for all of the cores. Each of the elements was subjected to linear regression analysis to determine the significance of changes in the concentrations of these metals from the bottom to the top of each core. Cores from seven lakes (Johnson, Santa Fe, Stewart, Truchas, Pecos Baldy, Lost, and Sugarloaf) were examined in detail because, with the exception of Lost Lake, the rest exhibited significant ($P < 0.1$) increases in the concentration of one or more metals. Lost Lake was representative of the Wheeler Peak study area which had relatively few enrichments in any of the lakes. Of note is, that with the exception of Sugarloaf Lake, all of the other lakes are located in the Pecos Wilderness study area. The histograms and line plots shown in Appendix F illustrate the increases exhibited in the cores and the data are summarized in table 13. The elements Pb, and Zn exhibit the greatest number of statistically significant ($P < 0.1$) enrichments in the more recent sediments which agrees qualitatively with Galloway et al. (1982) for the eastern USA. It has been observed that Pb and Zn often increase simultaneously in cores (Siccama et al. 1980). Trace metal increases in pb in the modern sediments of Pecos Wilderness area lakes are not surprising as these lakes are located downwind from the high population density corridor along the Rio Grande from Albuquerque to Espanola (figure 1). The only other lake showing a surface increase for lead was Middle Fork Lake which is also accessible by automobile on the edge of the Wheeler Peak Wilderness.

Sugarloaf Lake in the Brazos Uplift study area was the only man-made lake

TABLE 13

List of Lakes Exhibiting Increases in Trace Metal Concentrations in Recent Sections of Lake Sediment Cores*

Lakes	Cr	Fe	Mn	Ni	Hg	Pb	V	Zn
<u>Brazos Uplift</u>								
Sugarloaf	X			X	X		X	
<u>Pecos Wilderness Area</u>								
Johnson	X							
Pecos Baldy						X		X
Santa Fe		X				X		X
Stewart								X
Truchas		X	X			X	X	

---

* Significant for $R \geq 0.9$ (Sugarloaf); ≥ 0.805 (Johnson); ≥ 0.669 (Pecos Baldy, Santa Fe, Stewart, Truchas) at $P < 0.1$ (Appendix G)

studied. It was constructed in 1952 by the Chama Land and Cattle Company (Smith 1988) and, therefore, has been accumulating sediment for 35 years. As a consequence, the core was short (8 cm, table 3), but the elements Cr, Hg, Ni, and V showed increases toward the surface. Lead does not increase in the Sugarloaf core probably because this study area is not located downwind from large population centers as is the Pecos Wilderness study area. A study of Four Corners coal precipitator fly ash (Wangen and Wienke, 1976) showed enrichments fly ash for Cr, Cu, Hg, Ni, Pb, V, and Zn. Four of these elements also show increases in the Sugarloaf core. A survey of lakes in Rocky Mountain National Park in Colorado by Norton (1986) reported that only Pb had elevated deposition rates which the author suggested were due to local mining and smelting of sulfide ores and not long range transport.

Enrichment Factors. In addition to examining increases in trace metal concentrations from bottom to top in lake cores, enrichment factors were calculated to determine the relative contribution of anthropogenic sources to apparent trace metal increases. One form of enrichment factor (EF) used is defined as follows:

$$EF = (X/Y)\ \text{surface}/(X/Y)\ \text{bottom}$$

where X is the concentration of the element of interest and Y is the concentration of a "reference" element which is assumed to be independent of the sources of element X. In this work, we have used Fe as Y because its concentration is high in the sediment and, therefore, small changes in atmospheric deposition would not be expected to affect its concentration. In addition, the concentration of Fe throughout most cores was found to be relatively constant. A second form of enrichment factor used is called the cultural enrichment factor (CEF) after Robbins and Edgington (1977). The CEF is a ratio of the concentration of the element of interest in the top of the core to the same element in the bottom of the core. In this work, we have averaged the top two core sections and the bottom two core sections to obtain CEF values. Both EF and CEF values have been calculated for each element for all the lakes sampled and these values are tabulated in Appendix H. The enrichment factor data are summarized in table 14 where elements which exceeded ratios of 1.2 for both EF and CEF are indicated by X's. In the Wheeler Peak study area, only Middle Fork Lake has more than one metal enriched. Lead is of interest in Middle Fork Lake because it shows a significant increasing trend from bottom to top and, as mentioned previously, this lake is accessible by motor vehicles. Multiple enrichments (CEF, EF, and core trends) are summarized in table 15. In the Brazos Uplift area, Sugarloaf Lake shows multiple enrichments in Hg and V. The enrichment in Sugarloaf may be due to proximity to coal burning facilities in the Four Corners region as previously stated. Vanadium deposition has been strongly correlated with fossil fuel emissions in the eastern USA (Siccama et al. 1980). Consistent with increasing trace metal trends in the cores, the greatest number of enrichments for trace metals occurs in lakes in the Pecos Wilderness study area (table 14). Elemental enrichments of Cr, Hg, and Pb occurred in at least one-half of the lake sediment cores. In the Pecos Wilderness area, when enrichments and core trends are combined (table 15), recent atmospheric deposition is increasing for Cr, Hg, Pb, V, and Zn. Zinc is enriched in three of the lakes in the Pecos study area. As previously discussed, all of these metals are associated with increased air pollution from anthropogenic sources in the eastern USA.

<u>Comparison of Regional Heavy Metal Concentrations</u>. Metal concentrations were averaged for all sediments analyzed and the means are shown by region in table 16. The elements Cu, Fe, and Mn are higher than reported for the

TABLE 14

Lake Sediment Cultural Enrichment Factor (CEF) and Enrichment Factor (EF) Ratios Grouped by Study Area. The X's indicate that both values are > 1.2 and 0's indicate that both values are < 0.8. Values greater than 1.2 indicate enrichment in recent sediments and values less than 0.8 indicate depletion.

Lakes	Al	Cr	Cu	Hg	Mn	Ni	Pb	V	Zn
<u>Brazos Uplift</u>									
CLC Pond	0	0		X	0				0
Hidden	0		X	X			X		
Lagunitas #3	0								
Sugarloaf				X				X	X
<u>Pecos Wilderness Area</u>									
Johnson		X		X			X		
Katherine	X	X	X	X				X	
Nambe	X	X				X	X		
Pecos Baldy				0	X	0	X	0	X
Santa Fe				X	X				X
Spirit		X		0					
Stewart	0	0		0	0		X	X	X
Truchas	0			X		X			
<u>Wheeler Peak Wilderness Area</u>									
Horseshoe		X		0					
Lost	0	X				0			0
Middle Fork	X			0			X		
Williams	0			0		0	0		

TABLE 15

Trace Metal Enrichment Summary. The X's indicate elements which show enrichments for both CEF and EF and also exhibit increases in the sediment cores from bottom to top with significant ($P < 0.1$) regression coefficients.

Lake	Cr	Hg	Pb	V	Zn
Brazos Uplift					
Sugarloaf		X		X	
Pecos Wilderness Area					
Johnson	X				
Pecos Baldy			X		X
Santa Fe					X
Stewart					X

TABLE 16

Regional Comparison of Average Trace Metal Concentrations (ppm dry weight)

Data Source	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn
Granite*	77000	22	13	27700	.24	400	1	20	16	45
Heit**	DNP	DNP	26	1600	.03	DNP	9.6	28	27.3	117
Kahl***	63300	DNP	11	10700	DNP	277	DNP	91	DNP	130
Brazos	19000	30	51	25000	0.26	795	25	52	45	69
Pecos	37000	20	63	15300	0.19	364	15	78	30	65
Wheeler	28800	36	73	23500	0.16	357	20	89	53	88

* Reeves and Brooks (1978)
** Heit et al. (1984), Rocky Mountain National Park
*** Kahl et al. (1984), Eastern USA
DNP = Data Not Provided

eastern USA study while Cu, Fe, Hg, Ni, V, and Pb are higher than values found by Heit et al. (1984) in Rocky Mountain National Park lake sediments. An intercomparison of the metal concentrations in New Mexico lake sediments for the three study areas was made using paired t-tests and the results are summarized in table 17. The Wheeler Peak Wilderness lake sediments have significantly higher concentrations of Cr, Cu, Ni, Pb, V, and Zn than either the Pecos or Brazos area lake sediments. This may explain why so few enrichments are found for the Wheeler sediments; i.e., greater amounts of atmospheric deposition may be required to show significant changes. However, the Brazos area lake sediments exhibited higher background concentrations than the Pecos area sediments, yet Sugarloaf Lake sediments did exhibit several enrichments (tables 13-15).

Radiometric Dating of Sediment Cores. The cores from Santa Fe and Truchas lakes were subjected to gamma ray spectrometry for the isotopes Pb-210, Pb-214, and Cs-137 to determine the ages of the core section at various depths and to calculate sedimentation rates. The results of the isotopic analyses for the two lakes are summarized in table 18. Unexpectedly, the isotope Cs-137 exhibited measurable activity throughout the entire cores. This effect has been observed by Davis et al. (1984) and Anderson et al. (1987). Apparently Cs has much more mobility than expected in soft water, low alkalinity, or acidic lakes and tends to migrate both upward and downward in the core. The ages of various sections of the cores were thus estimated only from the excess Pb-210. The results are plotted in figures 10 and 11.

Age data calculated for the two cores are summarized in table 19. The sedimentation rates appear to decrease about 70 years ago in Santa Fe Lake and about 35 years ago in Truchas Lake. The metals Fe, Pb, and Zn show increases in the Santa Fe Lake core at the 50 mm depth. Assuming a sedimentation rate

TABLE 17

Summary of Paired t-test Comparisons of Metal Concentrations in Sediments by Regions. Plus values indicate the first region listed has a significantly ($P < 0.1$) higher value, while minus values indicate the second region has a significantly higher value. Zero values indicate no difference.

Regions	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn
Pecos - Wheeler	+	-	-	-	0	+	-	-	-	-
Pecos - Brazos	+	-	+	-	0	-	-	+	-	-
Brazos - Wheeler	-	-	-	+	0	+	+	-	-	-

TABLE 18

Activities of Pb-210, Pb-214, and Cs-137 in Santa Fe (SF) and Truchas Lakes (T) Cores. Values in pCi/g. Numbers following the symbols indicate core depth in cm.

Sample*	Pb-210	Pb-214	Excess Pb-210	Cs-137
SF-1,2	27.3	3.15	24.2	5.92
SF-3,5	13.3	3.28	10.0	2.07
SF-6,7	6.65	2.83	3.82	1.20
SF-8,9	4.52	3.19	1.33	1.00
SF-10,11,12	2.75	2.70	0.0046	0.77
SF-12,14,15	1.80	4.12	-2.32	0.75
SF-15,16,17	2.13	2.61	-0.48	0.82
T-1	30.9	6.88	24.0	9.64
T-2	26.0	4.04	22.0	10.3
T-3,4	20.8	4.19	16.7	5.77
T-8,9	7.0	4.32	2.67	1.17
T-9,10	7.20	4.35	2.08	1.16
T-11	5.53	3.93	1.61	1.20
T-13	5.23	4.16	1.07	0.75
T-15	6.56	5.61	0.94	1.11
T-18	5.50	4.50	0.99	0.81
T-19	5.61	3.87	1.75	0.72
T-20	4.64	4.54	0.095	0.82

* Core sections were combined in order to obtain enough sample for analysis

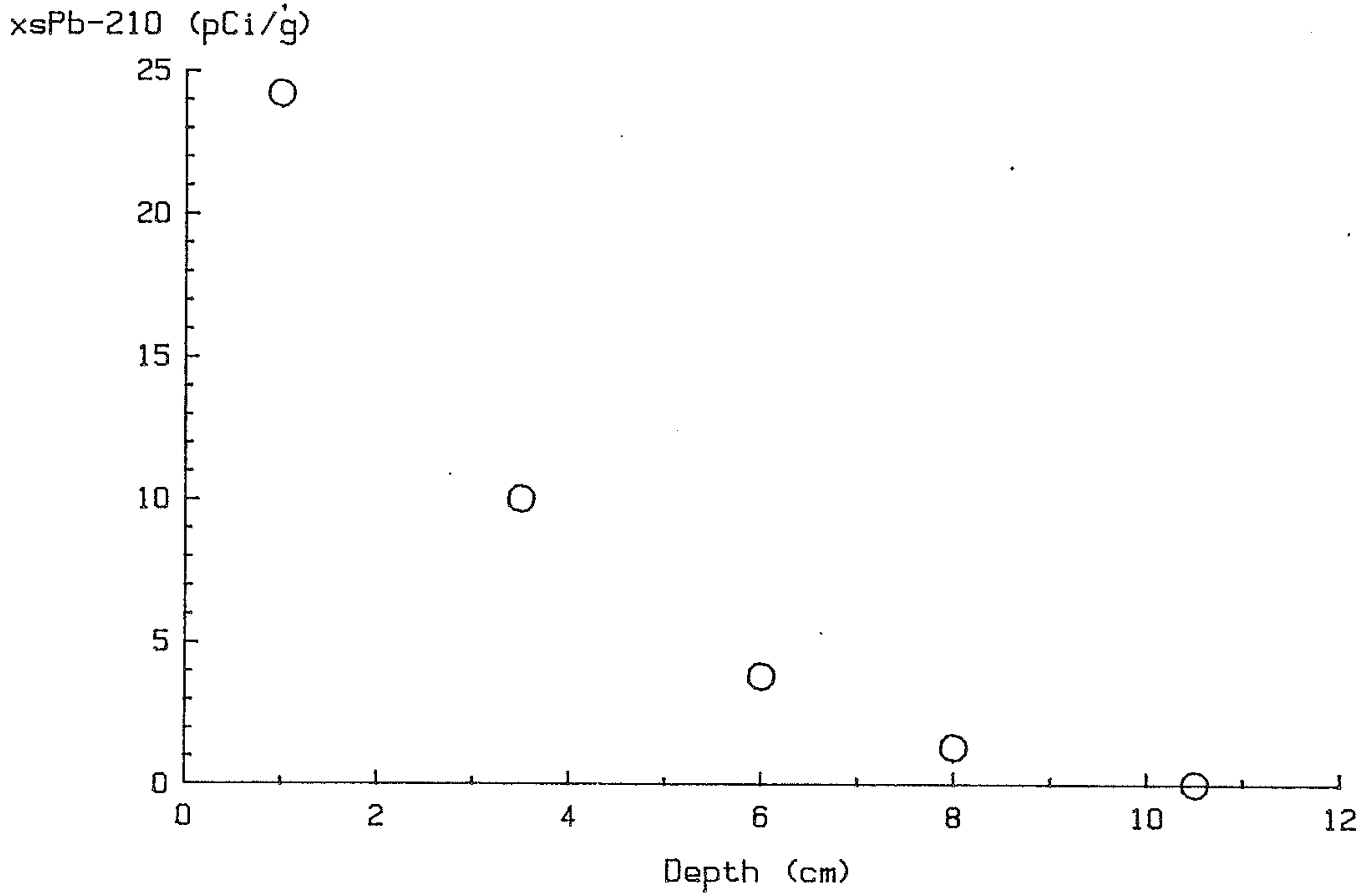


Fig. 10. Excess Pb-210 vs. Depth in the Santa Fe Lake Core

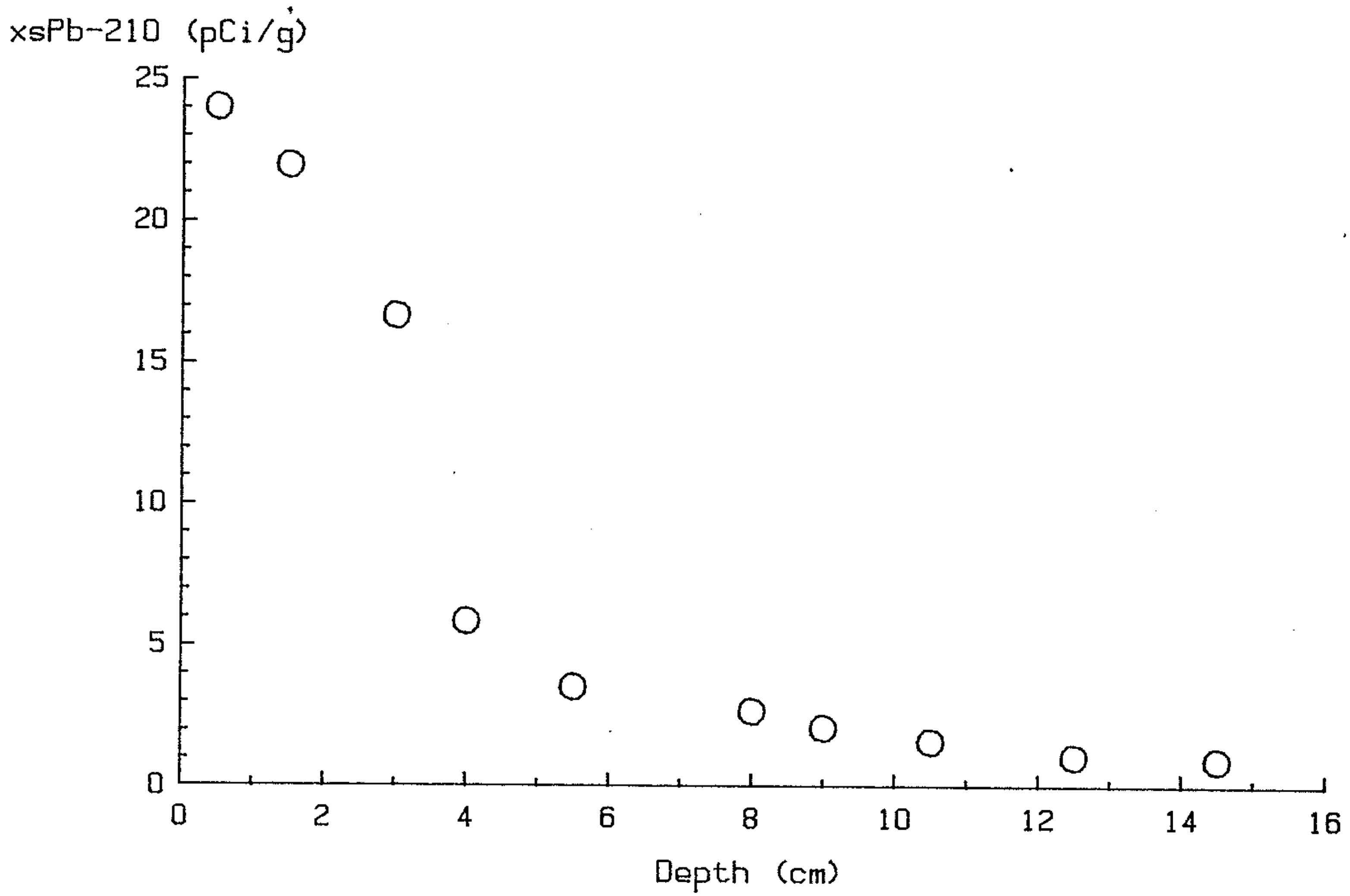


Fig. 11. Excess Pb-210 vs. Depth in the Truchas Lake Core

TABLE 19

Ages and Sedimentation Rates Calculated from Excess Pb-210 for Santa Fe and Truchas Lakes Cores

Lake	Depth (mm)	Age (y)	Sed. Rate (mm/y)
Santa Fe	20	29	0.7
	50	59	0.8
	70	94	0.7
	100	202*	0.5
Truchas	10	3	3.3
	35	12	3.0
	75	71	1.1
	120	100	1.2

* This value is probably invalid due to the limitation imposed by the number of half-lives. At 5-6 half-lives, the excess Pb-210 cannot be distinguished from the background Pb-210. Using a sedimentation rate of 0.7 mm/y, the age of the 100 mm sample would be 137 years.

of 0.7 to 0.8 mm/year, the increases would have begun about 60 years ago, corresponding to the late 1920's. The increases in Cu, Fe, and V in the Truchas Lake core are evident only in the top layer (10 mm depth) and would have occurred between three and twelve years ago. Lead increased in the top two samples of the Truchas Lake core, or top 50 mm, corresponding to 35 to 75 years ago. Truchas Lake is more isolated from human activity and the Middle Rio Grande population corridor, possibly causing the apparent delay in trace metal enrichment relative to Santa Fe Lake.

Biological Analysis

Planktonic Diatoms. Four lakes exhibiting low alkalinity were examined for pH preferences of the planktonic diatom species. The lakes chosen for analysis were Hidden, Santa Fe, Stewart, and Truchas; the mean alkalinities expressed as mg $CaCO_3$/l were 11.1, 7.2, 8.9, and 0.5 respectively. The pH values of Santa Fe and Truchas Lakes were decidedly acidic ranging from 5.6-7.1 and 5.4-5.5 respectively, while Hidden and Stewart Lakes had pH values ranging from 6.4-6.9.

Diatom species were assigned to preference categories based on an in-house compilation of species preferences reported by Anderson et al. (1986), Stokes and Yung (1986), Tolonen et al. (1986), Whitehead et al. (1986), Charles (1985), and Lowe (1974). This compilation currently contains entries for 529 taxa. However, the pH preferences of some diatoms are unknown at this time. The diatom pH preference categories used in this study were developed by Hustedt (1939) where:

acidobiontic - optimum distribution occurs at pH below 5.5
acidophilic - widest distribution at pH less than 7
indifferent - equal occurrences on both sides of pH 7

alkaliphilous - occur at pH about 7 with widest distribution at pH greater than 7

alkalibiontic - found only at pH greater than 7

Following the suggestions of several authors (Brakke 1984; Battarbee 1984), the term circumneutral was used in place of the term "indifferent" in order to alleviate ambiguity and to clearly reflect the widest distribution of these diatoms at pH values around 7.

The pH preferences of planktonic diatoms are summarized for four selected lakes in table 20. For each of the four lakes, complete species lists and their individual pH preferences are listed in Appendix I. No acidobiontic and only one species having alkalibiontic preferences were observed. The percentage of species with acidophilic preferences was higher in Santa Fe and Truchas Lakes than in Hidden and Stewart Lakes where alkaliphilic species were more common than those of circumneutral preference. In Truchas Lake, the number of acidophilic species represent almost half of all identified species with established preferences. The percentages of alkaliphilic species are low in Santa Fe and Truchas Lakes when compared to Hidden and Stewart Lakes. The lowest frequency of circumneutral species was found in Truchas Lake. Santa Fe and Truchas Lakes had lower pH values and lower acid neutralizing capacities than did Hidden or Stewart Lakes. Taken together, these data indicate that the pH values obtained for the lakes are probably indicative of mean conditions and that Santa Fe and Truchas Lakes may be experiencing acidification.

Sediment Diatoms. Two lake cores were examined for temporal changes in diatom species composition (Appendix J). The purpose of the analysis was to determine whether the lakes were exhibiting any signs of acidification or whether present conditions are similar to those which occurred before anthropogenic inputs of acid precursors commenced. The sections chosen for

TABLE 20

Summary of pH Preferences of Planktonic Diatoms in Selected High Altitude Lakes of Northern New Mexico

	Santa Fe	Stewart	Truchas	Hidden
Total Number of Species	12	13	18	13
Species with Known pH Preferences	9	10	15	12
Frequency (%)				
Acidobiontic	0	0	0	0
Acidophilic	22.2	10	46.7	0.0
Circumneutral	44.4	40	20	33.3
Alkaliphilic	33.3	50	33.3	58.3
Alkalibiontic	0	0	0	8.3

analysis were from the Truchas and Santa Fe Lake sediment cores. These particular cores were chosen because Truchas Lake has very low alkalinity and acidic pH; Santa Fe Lake had pH values below 6.5 in eight of thirteen different samples and alkalinities consistently less than 10 mg $CaCO_3/l$.

Acidobiontic and alkalibiontic species were absent from the core sections examined. Percentages of species falling into the different pH preference categories between the bottom and top of the Truchas core were not noticeably different (table 21). However, the relative frequencies of the diatoms in the recent sediments of the Truchas Lake core increased considerably for the circumneutral and acidophilous diatoms at the expense of the alkaliphilous species.

Sedimentary diatoms in the Santa Fe Lake core failed to exhibit any consistent changes in the percentages of species classified according to their pH preferences (table 21). However, when examined in terms of relative frequency, there was an increase in the percentage of cells belonging to species with circumneutral and acidophilic preferences (table 21). This upcore shift occurred at the expense of alkaliphilous species somewhere between 5 cm to 9 cm below the top of the core. Based on an estimated sedimentation rate of 0.8 mm per year, this shift occurred somewhere between 60 and 110 years ago. Analysis of available core sections between the 5 cm and 9 cm sections at some time in the future should provide a more precise estimate of the time at which the changes occurred.

The data from the core sections of the two more acidic lakes indicate that conditions in the lakes have changed at some point in the past to favor diatoms that are more acidophilous. A detailed examination of additional sections in both these cores is needed to pinpoint precisely when these changes occurred. Such changes have been observed in lakes that have

TABLE 21

Summary of pH Preferences for Diatoms in Selected Core Sections of Santa Fe (SF) and Truchas Lakes (T). Diatoms of unknown preference were eliminated from the calculations. Numbers following the abbreviations indicate core depth in cm.

	SF-1 (Top)	SF-5	SF-9	SF-14	SF-18 (Bottom)	T-1 (Top)	T-21 (Bottom)
Species Composition							
Number of Species	22	27	21	28	26	22	24
% Acidophilic	18.2	11.1	19	10.7	7.7	13.6	20.8
% Circumneutral	40.9	44.4	38.1	50	46.1	45.5	37.5
% Alkaliphilic	40.9	44.4	42.9	39.3	46.1	40.9	41.7
Relative Frequency							
Total Number of Cells	438	445	485	377	472	222	369
% Acidophilic	11.9	8.3	2.1	2.4	0.4	34.7	13.0
% Circumneutral	47.3	48.3	34.6	41.9	25.8	30.2	16.0
% Alkaliphilic	40.9	43.4	63.3	55.7	73.7	35.1	71.0

undergone acidification in eastern North America and northwestern Europe (Renberg and Hellberg 1982; Battarbee 1984; Dickman and Fortescue 1984; Charles 1985). The number of studies involving sedimentary diatoms in lakes of the western United States is very limited. Baron et.al. (1986) reported no historical influence on pH caused by acid deposition in four lakes from Rocky Mountain National Park, Colorado. Charles (1988) also reported no evidence of acidification for lakes in the Rocky Mountains and Sierra Nevada.

Benthic Macroinvertebrates. Sixteen taxa of benthic macroinvertebrates were identified in samples collected from fifteen of the lakes (Appendix K). Number of taxa/site varied from a low of one in Lake Katherine to a high of nine in Hidden Lake. Densities (standing crops) varied between $546/m^2$ in Lagunitas Lake to $14,854/m^2$ in Santa Fe Lake. Diversity indices were low for all lakes (< 2.44) and are similar to values found for shallow, lower elevation lakes in New Mexico (Potter 1982). However, the indices are well below values reported by Canton and Ward (1979) for shallow, lower elevation Colorado ponds. Neither the total number of taxa nor density were related to lake pH. Harvey and McArdle (1986) also reported no relationship between macroinvertebrate density and pH in Ontario lakes.

Dominant taxa included representatives of the Chironomidae (midges) which comprised up to 94% of the standing crop of organisms in Santa Fe Lake in March, 1988. Other dominant organisms included the tubificid worm, Limnodrilus hoffmeisteri, which was found in eleven of the lakes. The only organism found in the 20 m depth sample from Lake Katherine was L. hoffmeisteri. In the Stewart Lake sample collected from a depth of 10 m, 59% of the total number of organisms were worms. In this study, no correlation was found between worm density and total alkalinity concentrations while Raddum (1980) found that non-acidified lakes contained three to four times more worms when compared to acidified lakes.

Pea clams in the family Sphaeriidae (fingernail clams) were present in twelve of the fifteen lakes sampled. Taxonomy is still in progress (Ross 1987), but samples have been shown to contain representatives of the endangered Sangre de Cristo pea clam, Pisidium sp., and Lilljeborg's pea clam, P. lilljeborgii. Pea clams were abundant in most lakes and comprised 64% of the total number of organisms in Lost Lake.

When pea clam densities exceeded $100/m^2$ in shallow high mountain lakes (< 10 m deep), the densities were greater ($P < 0.05$) in high alkalinity lakes (> 250 μeq/l) than in low alkalinity lakes (< 250 μeq/l). This observation is consistent with the findings of Okland and Kuiper (1980) who reported that lakes with reduced alkalinity (pH below 5.0) had low or nonexistent fingernail clam populations. The impact of acidic precipitation on molluscs (snails and clams) is most dramatic because the calcareous shells are soluble at pH less than 7. Organisms become stressed because new $CaCO_3$ needed for shell growth must be precipitated at a rate faster than it can dissolve (Singer 1982).

The scud, or sideswimmer (Gammarus sp.), was found in five of the lakes and comprised 18% of the total number of organisms in Spirit Lake. In most of the lakes, scuds were observed along the shorelines, but no correlation was evident between numbers and pH or alkalinity concentrations. In laboratory tests with pH gradients, Gammarus sp. avoided a pH of 6.2 and stayed in a more alkaline pH environment of 9.6 (Costa 1967).

Benthic macroinvertebrate densities varied considerably throughout the year in Santa Fe Lake from a low of $868/m^2$ before ice-over to a high of $14,854/m^2$ four months later under ice cover. Most of the specimens collected during the ice-free months were late instars while those during the ice cover period were early instars. An exception to this latter case, was the presence of large, late instar larvae of Chironomus tentans throughout the year (except in June, 1988) which suggests a bivoltine life cycle. The peak density of 6,440/m^2 for C. tentans was followed by a complete loss of this midge after the period of lower pH in 1988.

Zooplankton. Thirty-one total zooplankton taxa were identified from twelve lakes (Appendix L); sixteen Crustacea/Insecta, and fourteen Rotifera. The number of zooplankton (excluding rotifers) taxa/lake was low; two each in Sugarloaf and Lagunitas Lakes to seven in Santa Fe Lake. Zooplankton densities varied considerably for those lakes sampled once; 167/m^3 in Lagunitas Lake to 103,953/m^3 in Pecos Baldy Lake. Dominant taxa included the water flea, Daphnia sp., which approached 80,000/m^3 in Pecos Baldy Lake. Low alkalinity lakes (< 250 μeq/l; pH < 7.40) when compared to high alkalinity lakes (> 430 μeq/l; pH > 7.55) supported reduced zooplankton densities which is consistent with the observations of others (National Research Council of Canada 1981; Sprules 1975; Raddum et al. 1980).

Santa Fe Lake zooplankton were sampled eleven times during a one year period from July 1987 to June 1988. Copepoda maximum densities (59,000/m^3) occurred in November after ice formation. Numbers continued to decline throughout the year until a low density (15/m^3) was reached after turnover in late May. Cladocera samples consisted primarily of Daphnia sp. which exhibited a bimodal population maximum in September after fall overturn and in February under ice cover. Population numbers decreased by 80% in November after 0.15 m of ice had formed. The highest population density (28,000/m^3) was reached under maximum ice-cover of 0.9 m in February. In mid-May, the population was reduced by 99% after ice-melt. This sharp decrease in Daphnia sp. numbers occurred during the period of low pH (5.7) associated with snow and ice-melt. Daphnia sp. are generally eliminated at pH values ranging from 5.2 to 5.6 (Brakke 1984; Bruns and Wiersma 1988).

Lake Basin Geology and X-ray and Particle Size Analysis of Lake Core Sediments

In the Pecos study area, the lakes were located in Precambrian environments characterized by quartz diorite, biotite gneisses and granites (Appendix M). The lone exception was Pecos Baldy Lake which was slightly outside the Precambrian rocks and located in Paleozoic sedimentary rocks. Lakes in the Brazos region lie in a varied collection of volcanic and volcanoclastic sediments (Appendix M). The lake basins in the Wheeler Peak study area consist mainly of Precambrian amphibole gneisses and granite with minor Paleozoic outcrops of sandstones, limestones, and shales (Appendix M) which provide some neutralization capacity.

Sediment and clay mineralogies for lake cores are summarized in Appendix M. The clay minerals identified were dominated by illite, kaolinite, chlorite, and some mixed-layer illite/smectite. A variety of minerals were found in the lake sediments with quartz, plagioclase, and muscovite found most commonly. Particle size analysis of sediments found in the cores at various depths are summarized in Appendix M. Most of the lake sediments were characterized by a large silt-sized fraction. Both Lake Katherine and Lost Lake had a large fraction of sand-sized material in the upper sections of the cores. These lakes have very steep, rocky basins with little plant cover and are probably subject to considerable sediment deposition by abrasion of the basin rocks.

CONCLUSIONS AND SUMMARY

The following conclusions are organized with reference to the project objectives stated on page 9 of this report. The pH values and buffer capacities of the lakes show a wide range of conditions. Seven of the eight lakes in the Pecos Wilderness study area had average alkalinity values < 250 μeq/l (sensitive) with one lake (Truchas) averaging 10 μeq/l indicating little or no buffering capacity. The pH values for the Pecos area lakes were between 6.0 and 7.0, with the exceptions of Truchas Lake (average pH = 5.4) and Santa Fe Lake which ranged from pH 5.7 - 7.2 during the study period. The low buffer capacity lakes were all located in Precambrian rock environments. Only Hidden Lake in the Brazos study area had an alkalinity average < 250 μeq/l, and none of the lakes in the Wheeler study area exhibited low alkalinities or pH values. The lakes located in basins containing sedimentary rocks were insensitive to acidification by precipitation (primarily measured for snow) which often had pH values < 5.0 even late in the year. Sulfur isotope analysis of sulfate in lake water and snow correlate well, indicating the primary source of sulfate to the lakes is from atmospheric deposition. Santa Fe Lake was studied over a one year period to monitor temporal changes and showed clear evidence of receiving an acid pulse from snow melt resulting in short-term depressions in pH and alkalinity. In addition, the density of the dominant zooplankton organism, <u>Daphnia</u> sp., in Santa Fe Lake decreased significantly shortly after the acid pulse occurred.

Trace metal enrichments were evident in the upper portions of a number of lake sediment cores, especially for elements associated with industrialization and man's activities (Pb, Cu, Zn, V, Ni). The most likely pathway for these elements to enter the lake sediments is through atmospheric deposition. Dates for sediment layers in the cores using Pb-210 chronology established trace metal increases in the Santa Fe Lake core beginning about 70 years ago and those in Truchas Lake about 10-20 years ago.

Planktonic diatom analysis indicates that measured pH values obtained accurately reflect the present condition of the lakes. Sediment diatom data from core samples of the most acidic and low alkalinity lakes (Truchas and Santa Fe) indicate a change in diatom species from more alkaliphilous to acidiphilous preferences has occurred. Total numbers of taxa and density of benthic macroinvertebrates were not related to lake pH, although pea clam densities were lower in low alkalinity lakes (< 250 μeq/l) than in high alkalinity lakes.

RECOMMENDATIONS

This study was essentially a reconnaissance survey of the biological and chemical baseline conditions of wilderness lakes located in three areas of northern New Mexico. A number of results suggest that the potential for ecological damage from acid deposition may be high in some of the more sensitive lakes. As consequence, the following recommendations are made:

I. Detailed age-dating, diatom, and trace metal analysis of lake cores from other lakes are needed to determine the extent of recent changes because of the lack of historical data.

II. Santa Fe Lake was subjected to an acid pulse associated with snow melt and this lake should receive continued study for biological and chemical modifications.

III. Stable sulfur isotope analysis of precipitation may be an excellent tool for tracing the source(s) of sulfate to the lakes and this work should also be continued.

IV. A detailed geochemical modeling of lake water chemistry, basin geology, and sediment mineralogy should be undertaken for the sensitive lakes to determine future potential for acidification.

BIBLIOGRAPHY

American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater. 16th Edition. American Public Health Association, Washington, DC, 1268 pp.

Anderson, D.S., R.B. Davis, and F. Berge. 1986. Relationships between diatom assemblages in lake surface-sediments and limnological characteristics in southern Norway. In Diatoms and Lake Acidity, ed. J.P. Smol et al., 97-114 pp. Dordrecht, Netherlands: Dr. W. Junk Publishers.

Anderson, R.F., S.L. Schiff, and R.H. Hesslein. 1987. Determining sediment accumulation and deposition rates using ^{210}Pb, ^{137}Cs, and other tracers: Problems due to postdepositional mobility or coring artifacts. Can. J. Fish. Aquat. Sci. 44(Suppl. 1):231-250.

Ashbaugh, L.L., L.P. Myrup, and R.G. Flocchini. 1984. A principal component analysis of sulfur concentrations in the western United States. Atmos. Environ. 18:783-791.

Austin, G. 1987. Personal Communication, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

Baron, J. 1983. Comparative water chemistry of four lakes in Rocky Mountain National Park. Water Resour. Bull. 19:897-902.

Baron, J., S.A. Norton, D.R. Beeson, and R. Herrmann. 1986. Sediment diatom and metal stratigraphy from Rocky Mountain lakes with special reference to atmospheric deposition. Can. J. Fish. Aquat. Sci. 43:1350-1362.

Battarbee, R.W. 1984. Diatom analysis and the acidification of lakes. Phil. Trans. R. Soc. Lond. B305:451-477.

Beamish, R.J., and H.H. Harvey. 1972. Acidification of the LaCloche Mountain Lakes, Ontario, and resulting fish mortalities. J. Fish Res. Bd. Can. 29:1131-1143.

Beamish, R.J., W.L. Lockhart, J.C. Van Loon, and H.H. Harvery. 1975. Long-term acidification of a lake and resulting effects on fishes. Ambio. 5:98-102.

Bertine, K.K., and M.F. Mendeck. 1978. Industrialization of New Haven, Conn., as recorded in reservoir sediments. Environ. Sci. Technol. 12:201-207.

Brakke, D.F. 1984. Acidification history and prediction using biological indices. Verh. Internat. Verein. Limnol. 22:1391-1395.

Brandvold, D.K., J.A. Brierley, and C.J. Popp. 1973. Chemical and biological character of Rio Grande water in the Bosque del Apache Wildlife Refuge. New Mexico Water Resources Research Institute, Report No. 030, New Mexico State University, Las Cruces, New Mexico.

Brandvold, L. 1978. Mercury in New Mexico Surface Waters. Socorro, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular No. 62.

Brezonik, P.L., T.L. Crisman, and R.L. Schulze. 1984. Planktonic communities in Florida softwater lakes of varying pH. Can. J. Fish. Aquat. Sci. 41:46-56.

Brinkhurst, R.O., K.E. Chua, and E. Batoosingh. 1969. Modifications in sampling procedures as applied to studies on the bacteria and tubificid oligochaetes inhabiting aquatic sediments. J. Fish. Res. Bd. Can. 26:2581-2593.

Bruns, D.A. and G.B. Wiersma. 1988. Laboratory acidification of a crustacean zooplankton assemblage from a Rocky Mountain subalpine lake (U.S.A.). Environ. Toxicol. Chem. 7:807-814.

Buchholz, A.E., C.I. Verplough, and J.L. Smith. 1982. A method for the simultaneous measurement of less than a part-per-million of chloride, nitrate, and sulfate in aqueous samples by nonsuppressed ion chromatography. J. Chromatogr. Sci. 20:449-501.

Canton, S.P., and J.V. Ward. 1979. Environmental effects of western coal surface mining. Part 1 - The limnology and biota of mine spoils ponds in northwest Colorado. EPA-600/3-79-124. USEPA, Duluth, Minnesota, 39 pp.

Charles, D.F. 1985. Relationships between surface sediment diatom assemblages and lake water characteristics in Adirondack Lakes. Ecology. 66(3):994-1011.

Charles, D.F. 1988. Lake acidification trends in low-alkalinity regions of the U.S. based on paleoecological analyses of diatoms and chrysophytes. Abstracts of Papers for the 1988 Annual Meeting, American Society of Limnology and Oceanograpy Inc. Boulder, Colorado. June 12-16, 1988.

Confer, J.L., R. Kaaret, and G.E. Likens. 1983. Zooplankton diversity and biomass in recently acidified lakes. Can. J. Fish. Aquat. Sci. 40:36-42.

Costa, H.H. 1967. Responses of Gammarus pulex (L.) to modified environment. II. Reactions to abnormal hydrogen ion concentrations. Crustaceana. 13:1-10.

Davis, R.B., C.T. Hess, S.A. Norton, D.W. Hanson, K.D. Hoagland, and D.S. Anderson. 1984. ^{137}Cs and ^{210}Pb dating of sediments from soft-water lakes in New England (U.S.A.) and Scandinavia, a failure of ^{137}Cs dating. Chemical Geology. 44:151-185.

Dehn, M. 1983. Lead-210 and Cesium-137 dating of sediments from the Rio Puerco, New Mexico. Master's thesis, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Dickman, M., and J. Fortescue. 1984. Rates of lake acidification inferred from sediment diatoms for eight lakes located north of Lake Superior, Canada. Verh. Internat. Verein. Limnol. 22:1345-1356.

Dillon, P.J., N.D. Yan, and H.H. Harvey. 1984. Acidic deposition: Effects on aquatic ecosystems. In CRC Critical Reviews in Environmental Control. ed. C.P. Straub, Vol. 13(3), 167-194 pp. Boca Raton: CRC Press.

Duff, D.A., and L.E. Siverts. 1969. Pecos Wilderness water quality and wildlife inspection field trip. United States Forest Service, Santa Fe, New Mexico, July/August.

Eilers, J.M., G.E. Glass, K.E. Webster, and J.A. Rogalla. 1983. Hydrologic control of lake susceptibility to acidification. Can. J. Fish. Aquat. Sci. 40:1896-1904.

Electric Power Research Institute. November 1983, Vol. 8 (9). Acid Rain Research: A Special Report, 1-64 pp.

Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020.

Erdmann, G., and W. Soyka. 1979. The Gamma Rays of the Radionuclides. New York: Verlag Chemie, 862 pp.

Evans, H.E., P.J. Smith, and P.J. Dillon. 1983. Anthropogenic zinc and cadmium burdens in sediments of selected southern Ontario lakes. Can. J. Fish. Aquat. Sci. 40:570-579.

Galloway, J.N., C. Schofield, N.E. Peters, G.R. Hendrey, and E.R. Altwicker. 1983. Effects of atmospheric sulfur on the composition of three Adirondack lakes. Can. J. Fish. Aquat. Sci. 40:799-806.

Galloway, J.N., J.H. Thornton, S.A. Norton, H.L. Volchok, and R.A.N. McLean. 1982. Trace metals in atmospheric deposition review and assessment. Atmos. Environ. 16:1677-1700.

Galloway, J.N., S.A. Norton, and M.R. Church. 1983. Freshwater acidification from atmospheric deposition of sulfuric acid: A conceptual model. Environ. Sci. Technol. 17:541A-545A.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A review. Trans. Amer. Fish. Soc. 110:669-707.

Hall, R.J., G.E. Likens, S.B. Fiance, and G. Hendrey. 1980. Experimental acidification of a stream in the Hubbard Brook Experimental Forest, New Hampshire. Ecology. 61:976-989.

Harte, J., G.P. Lockett, R.A. Schneider, H. Michaels, and C. Blanchard. 1985. Acid precipitation and surface-water vulnerability on the western slope of the high Colorado Rockies. Water, Air, and Soil Pollution. 25:313-320.

Harvey, H.H., and J.M. McArdle. 1986. Composition of the benthos in relation to pH in the LaCloche Lakes. Water, Air, and Soil Pollution. 30:529-536.

Havas, M., and T.C. Hutchinson. 1982. Aquatic invertebrates from the Smoking Hills, N.W.T.: Effect of pH and metals on mortality. *Can. J. Fish. Aquat. Sci*. 39:890-903.

Heit, M., C. Klusek, and J. Baron. 1984. Evidence of deposition of anthropogenic pollutants in remote Rocky Mountain lakes. *Water, Air, and Soil Pollution*. 22:403-416.

Henriksen, A. 1979. A simple approach for identifying and measuring acidification of freshwater. *Nature*. 178:542-545.

Hoefs, J. 1980. *Stable Isotope Geochemistry*. 2nd Edition. New York: Springer-Verlag, 208 pp.

Hustedt, F. 1939. Systematische and okologische Untersuchungen uber die Diatomeenflora von Java, Bali und Sumatra. *Arch. fur Hydrobiol. Suppl*. 16:274-394.

Janitzky, P. 1986. Particle size analysis. *USGS Bulletin*. 1648:12.

Kahl, J.S., S.A. Norton, and J.S. Williams. 1984. Chronology magnitude and paleolimnological record of changing metal fluxes related to atmospheric deposition of acids and metals in New England. In *Geological Aspects of Acid Deposition*, ed. by O.P. Bricker, 23-35 pp. Boston: Butterworth Publishers.

Kramer, J., and A. Tessier. 1982. Acidification of aquatic systems: A critique of chemical approaches. *Environ. Sci. Technol*. 16:606A-615A.

Kwiatkowski, R.E., and J.C. Roff. 1976. Effects of acidity on the phytoplankton and primary productivity of selected northern Ontario lakes. *Can. J. Bot*. 54:2546-2561.

Landers, D.H., J.M. Eilers, D.F. Brakke, and P. E. Kellar. 1988. Characteristics of acidic lakes in the eastern United States. *Verh. Internat. Verein. Limnol*. 23:152-162.

Lewis Jr., W.M., and M.C. Grant. 1980. Acid precipitation in the western United States. *Science*. 207:176-177.

Lewis Jr., W.M., M.C. Grant, and J.F. Saunders, III. 1984. Chemical patterns of bulk atmospheric deposition in the State of Colorado. *Water Resour. Res*. 20:1691-1704.

Likens, G.E., R.F. Wright, J.N. Galloway, and T.J. Butler. 1979. Acid rain. *Sci. Amer*. 241(4):43-41.

Lind, O.T. 1979. *Handbook of Common Methods in Limnology*. 2nd Edition. St. Louis, Missouri: C.V. Mosby Co., 199 pp.

Logan, R.M., J.C. Derby, and L.C. Duncan. 1982. Acid precipitation and lake susceptibility in the central Washington Cascades. *Environ. Sci. Technol*. 16:771-775.

Long, A. 1988. Personal communication, University of Arizona, Tucson, Arizona.

Lowe, R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. EPA-670/4-74-005. USEPA, Cincinnati, Ohio.

Malley, D.F., D.L. Findlay, and P.S.S. Chang. 1982. Ecological effects of acid precipitation on zooplankton. In Acid Precipitation Effects on Ecological Systems, ed. F.M. D'Itri, 297-327. Ann Arbor, Michigan: Ann Arbor Pubishers.

Michaels, H.M., C.L. Blanchard, A. Bradman, and J. Harte. 1987. Investigation of snow pack chemistry on the western slope of the Colorado Rockies. Energy and Resources Group, Report No. ERG-87-1, University of California, Berkeley, California.

Melack, J.M., J.L. Stoddard, and D.R. Dawson. 1983. Acid precipitation and buffer capacity of lakes in the Sierra Nevada, Caifornia. In Acid Rain - A Water Resource Issue for the 80's, ed. R. Hermann and A.I. Johnson, 35-41 pp. Denver, Colorado: American Water Resources Association International Symposium.

National Council on Radiation Protection and Measurements. 1978. A Handbook of Radioactivity Measurement Procedures. Washington, DC: National Council on Radiation Protection and Measurements Report 58, 504 pp.

National Research Council of Canada. 1981. Acidification in the Canadian Aquatic Environment. NRCC No. 18475. National Research Council of Canada, Ottawa, 369 pp.

New Mexico Environmental Improvement Division, Air Quality Bureau. The 1981-1982 State of New Mexico Ambient Air Quality Data Summary. Santa Fe, New Mexico, 24 pp.

New Mexico Geological Society. New Mexico Highway Geologic Map. 1982. New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

Nielson, H. 1974. Isotope composition of the major contributors to atmospheric sulfur. Tellus. 20:213.

Niemann, B.L. 1985. Critical Analysis of Regional Acid Deposition Source-Receptor Relationships for Smelters in the Intermountain West. Presented at the International Conference on Acidic Precipitation, Muskoka, Ontario.

Norton, S.A. 1986. A review of the chemical record in lake sediment of energy related air pollution and its effects on lakes. Water, Air, and Soil Pollution. 30:331-345.

Novo-Gradac, K. 1983. Trace metal and radionuclide distributions in recent sediments of the Rio Puerco, Rio San Jose, and Paguate Reservoir in the Grants mineral belt. Master's thesis, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Nriagu, J.O., H.K. Wong, and R.D. Coker. 1982. Deposition and chemistry of pollutant metals in lakes around the smelters at Sudbury, Ontario. Environ. Sci. Technol. 16:551-560.

Nuclear Data Corporation. 1980. ND6600 Operational Instruction Documentation. Schaumberg, Illinois: Nuclear Data Corporation.

Okland, K.A., and J.G.J. Kuiper. 1980. Distribution of small mussels (Sphaeriidae) in Norway, with notes on their ecology. Haliotis. 10(2):109.

Oppenheimer, M., C.B. Epstein, and R.E. Yuhnke. 1985. Acid deposition, smelter emissions, and the linearity issue in the western United States. Science. 229:859-862.

Popp, C.J., and F. Laquer. 1980. Trace metal transport and partitioning in the suspended sediments of the Rio Grande and tributaries in central New Mexico. Chemosphere. 9:89-98.

Popp, C.J., C.M. Jensen, D.K. Brandvold, and L.A. Brandvold. 1982. Precipitation analysis in central New Mexico. In Energy and Enviromental Chemistry. Acid Rain, ed. L.H. Keith, 89-101 pp. Ann Arbor, Michigan: Ann Arbor Science.

Popp, C.J., J.W. Hawley, and D.W. Love. 1983. Trace Metals and Radionuclides in Recent Sediments in the Grants Mineral Belt, New Mexico. Technical Completion Report, Office of Surface Mining, Department of the Interior, Washington, DC. 130 pp.

Popp, C.J., R.W. Ohline, D.K. Brandvold, and L.A. Brandvold. 1984. Nature of precipitation and atmospheric particulates in central and northern New Mexico. In Deposition Both Wet and Dry. Acid Precipitation Series, ed. B.B. Hicks, Volume 4, 79-95 pp. Boston: Butterworth Publishers.

Popp, C.J., D.K. Brandvold, A. Long, L. Warneke. 1986. Acidic precipitation in western North America: Trends, sources, and altitude effects in New Mexico 1979-1985. Water, Air, and Soil Pollution. 30:125-133.

Potter, D.A. 1982. New Mexico Clean Lakes Program: Classification Phase I, Final Report. New Mexico Environmental Improvement Division, Santa Fe, New Mexico EID/WPC/-82/4, 75 pp. + Appendix.

Potter, D.A. 1988. Personal communication, New Mexico Environmental Improvement Division, Santa Fe, New Mexico.

Potter, L., D. Kidd, and D. Standiford. 1975. Mercury levels in Lake Powell. Environ. Sci. Tech. 9:41-46.

Raddum, G.G. 1980. Comparison of benthic invertebrates in lakes with different acidity. In Ecological Impact of Acid Precipitation, ed. D. Drablos and A. Tollan, 330-331 pp. Sandefjord, Norway: SNSF Project.

Raddum, G.G., A. Hoback, E.R. Lomsland, and T. Johnsen. 1980. Phytoplankton and zooplankton in acidified lakes in south Norway. In *Ecological Impact of Acid Precipitation*, ed. D. Drablos and A. Tollan, 332-333 pp. Oslo, Norway: SNSF Project.

Rahel, F.J., and J.J. Magnuson. 1983. Low pH and the absence of fish species in naturally acidic Wisconsin lakes: Inferences for cultural acidification. *Can. J. Fish. Aquat. Sci*. 40:3-9.

Reeves, R.D., and R.R. Brooks. 1978. Trace Element Analysis of Geologic Materials. New York: John Wiley and Sons. 421 pp.

Renberg, I. 1986. Concentration and annual accumulation values of heavy metals in lake sediments: Their significance in studies of the history of heavy metal pollution. *Hydrobiol*. 143:379-385.

Renberg, I., and T. Hellberg. 1982. pH history of lakes in southwestern Sweden, as calculated from the subfossil diatom flora of the sediment. *Ambio*. 11:30-33.

Robbins, J.A., and D.N. Edgington. 1977. Argonne National Laboratory Report No. ANL-76-88, Part III, 65-71 pp.

Roff, J.C., and R.E. Kwiatkowski. 1977. Zooplankton and zoobenthos communities of selected northern Ontario lakes of different acidities. *Can. J. Zool*. 55:899-911.

Ross, J. 1987. Personal communication. United States Forest Service, Taos, New Mexico.

Schery, S.D. 1980. Determination of Lead-210 in environmental samples by gamma spectrometry with high purity Germanium detectors. *Analytical Chemistry*. 52:1957-1958.

Schindler, D.W. 1988. Effects of acid rain on freshwater ecosystem. *Science*. 239:149-157.

Schindler, D.W., R. Wagemann, R.B. Cook, T. Ruszczynski, and J. Prokopowich. 1980. Experimental acidification of Lake 223, Experimental Lakes Area: Background data and the first three years of acidification. *Can. J. Fish. Aquat. Sci*. 37:342-354.

Schlesinger, W.H., and W.T. Peterjohn. 1988. Ion and sulfur-iostope ratios in arid soils subject to wind erosion in the southwestern USA. *Soil Science Society of America Journal*. 52(1):54-58.

Siccama, T.G., W.H. Smith, and D.L. Mader. 1980. Changes in gold, zinc, copper, dry weight, and organic matter content of the forest floor of white pine stands in central Massachusetts over 16 years. *Environ. Sci. Technol*. 14:54-56.

Singer, R. 1982. Effects of acidic precipitation on benthos. In Acid Precipiation Effects on Ecological Systems, ed. F.M. Ditri, 329-363 pp. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Smith, L. 1988. Personal communication, Chama Land and Cattle Company, Chama, New Mexico.

Somers, K.M., and H.H. Harvey. 1984. Alteration of fish communities in lakes stressed by acid deposition and heavy metals near Wawa, Ontario. Can. J. Fish. Aquat. Sci. 41:20-29.

Sprules, W.G. 1975. Midsummer crustacean zooplankton communities in acid-stressed lakes. J. Fish. Res. Bd. Can. 32:389-395.

Stokes, P.M., and Y.K. Yung. 1986. Phytoplankton in selected LaCloche (Ontario) lakes, pH 4.2-7.0, with special reference to algae as indicators of chemical characteristics. In Diatoms and Lake Acidity, ed. by J.P. Smol et al., 57-72 pp. Dordrecht, Netherlands: Dr. W. Junk Publishers.

Stumm, W., and J.J. Morgan. 1981. Aquatic Chemistry. 2nd Edition. New York: John Wiley and Sons, Inc., 780 pp.

Tolonen, K., M. Liukkonen, R. Harjula, and A. Patila. 1986. Acidification of small lakes in Finland documented by sedimentary diatom and chrysophycean remains. In Diatoms and Lake Acidity, ed. J.P. Smol et al., 169-200 pp. Dordrecht, Netherlands: Dr. W. Junk Publishers.

Turk, J.T. 1983. An evaluation of trends in the acidity of precipitation and the related acidification of surface water in North America. USGS Water-Supply Paper 2249:18.

Turk, J.T., and D.B. Adams. 1983. Sensitivity to acidification of lakes in the Flat Tops Wilderness Area. Colorado Water Resour. Res. 19:346-350.

Van Der Werff, A. 1955. A new method of concentrating and cleaning diatoms and other organisms. Assoc. Theor. Appl. Lim. 12:276-277.

Wangen, L.E. and C.L. Wienke. 1976. A Review of Trace Element Studies Related to Coal Combustion in the Four Corners Area of New Mexico. LA-6401-MS. Los Alamos National Laboratory, New Mexico, July, p. 14.

Whitehead, D.R., D.F. Charles, S.T. Jackson, S.E. Reed, and M.C. Sheehan. 1986. Late-glacial and Holocene acidity changes in Adirondack (New York) Lakes. In Diatoms and Lake Acidity, ed. J.P. Smol et al., 251-274. Dordrecht, Netherlands: Dr. W. Junk Publishers.

Yan, N.D. 1983. Effects of changes in pH on transparency and thermal regimes of Lohi Lake, near Sudbury, Ontario. Can. J. Fish. Aquat. Sci. 40:621-626.

Appendix A. Lake Water Depth Profiles for Temperature, Dissolved Oxygen, and Conductivity, 1986-1988

Appendix A. Water quality depth profile for temperature, dissolved oxygen and conductivity, 1986-88

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/1	Conductivity* $\mu S/cm^2$
CLC Pond 06-21-87	0.6	(Very shallow; no profiles obtained)		
Hidden				
06-20-87	Surface	13.5	7.2	48
	1	13.5	7.3	49
	2	12.0	7.6	48
	3	11.0	8.1	47
	4	8.0	7.5	33
	5	6.3	4.7	57
	6	5.5	0.5	64
Lagunitas #3				
06-23-87	Shoreline	20	---	94
	Surface	18.5	---	94
	1	17.5	---	92
	2	17	---	93
	2.5	16.3	---	95
Sugarloaf				
06-22-87	Surface	16	8.6	62
	1	15	8.8	62
	2	12	8.0	58
	4	8	1.8	57
	5	7.5	0.3	58
Johnson				
07-08-87	Shoreline	15	---	34
	Surface	14.5	6.9	31
	1	12.8	7.1	32
	2	12.0	---	33
	3	10.6	7.1	34
	4	8.9	---	35
	5	7.1	7.0	36
	6	7.0	---	36
	7	6.5	4.9	37

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/l	Conductivity* µS/cm^2
Katherine 08-19-86	Surface	13.1	7.1	27
	1	13.1	—	27
	2	13.1	—	27
	3	12.8	—	28
	4	12.5	—	28
	5	12.0	—	29
	6	11.8	—	29
	7	10.2	—	30
	8	8.4	—	31
	9	7	—	32
	10	6	10.1	33
	11	5	—	33
	12	4.9	—	34
	13	4.8	—	34
	14	4.8	—	34
	15	4.95	—	34
	20	—	2.3	—
Katherine 07-07-87	Shoreline	12	—	26
	Surface	11	7.5	25
	1	11	7.5	25
	2	10.9	—	27
	3	10	7.4	27
	4	9.8	—	29
	5	7.8	7.9	29
	6	6.8	—	29
	7	6.0	—	32
	8	5.3	8.6	34
	9	4.8	—	34
	10	4.5	—	34
	11	4.1	6.9	35
	12	4.0	—	35
	13	3.8	—	37
	14	3.5	5.4	37
	17	—	3.2	—
	20	—	1.9	—
	23	—	0.7	—

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/1	Conductivity* $\mu S/cm^2$
Nambe				
07-26-86	Surface	10	7.9	34
	0.5	10	7.6	34
	1	8.8	7.6	35
Pecos Baldy				
08-17-86	Surface	16	7.4	105
	1	15.9	----	105
	2	14.9	7.45	103
	3	14.5	----	100
	3.8	14.4	7.05	96
Santa Fe				
05-25-86	Surface	4.8	5.9	31
	1	4.8	5.0	31
	2	5.0	4.8	31
	3	5.0	5.0	31
	4	5.0	5.0	38
	5	5.0	5.4	45
	6	5.0	5.9	75
	7	5.0	6.2	89
Santa Fe				
07-01-87	Surface	13.5	7.8	32
	1	12	7.8	30
	2	12	8.0	30
	3	10.2	8.7	35
	4	8.9	8.9	40
	5	7.2	7.9	43
	6	6.0	5.1	45
Santa Fe				
08-11-87	Surface	16.5	5.8	--
	1	16.0	6.7	--
	2	15.5	6.4	--
	3	15.5	6.6	--
	4	15.0	6.1	--
	5	15.0	6.6	--

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/1	Conductivity8 μS/cm^2
Santa Fe 09-03-87	Surface	11.5	7.1	37
	1	11.5	6.9	37
	2	11.1	—	37
	3	11.0	7.0	37
	4	11.0	—	37
	5	10.9	—	37
	6	10.9	7.1	37
	7	10.9	—	37
Santa Fe 10-16-87	Surface	11.5	7.6	30
	1	12.2	7.6	30
	2	12.5	7.6	30
	3	12.5	—	30
	4	13	7.7	32
	5	13	—	29
	6	12.8	7.6	36
Santa Fe 11-12-87	Surface	0.8	9.2	56
	1	2.5	7.9	49
	2	2.8	7.4	41
	3	3.0	—	41
	4	3.2	7.3	35
	5	3.5	—	35
	6	4.0	6.9	53
Santa Fe 12-16-87	Surface	0.0	6.2	36
	1	1.5	6.3	35
	2	3.0	5.6	34
	3	3.0	—	37
	4	3.3	3.5	40
	5	3.5	3.2	40

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/l	Conductivity* µS/cm^2
Santa Fe 02-11-88	Surface	0	4.8	38
	1	0	4.8	34
	2	2	---	36
	2.5	-	4.7	--
	3	3	---	42
	4	3.2	1.1	44
	5	3.5	0.9	43
Santa Fe 03-17-88	Surface	0.2	---	34
	1	0.5	3.1	34
	2	1.1	1.4	37
	3	2.6	0.4	39
	4	3.0	0.6	44
	5	3.5	---	64
	5.5	4.0	0.5	82
Santa Fe 04-09-88	Surface	0.5	4.2	24
	1	0.3	---	24
	1.5	---	2.1	--
	2	1.2	---	27
	3	3	0.9	29
	4	3.3	0.6	36
	5	4	---	47
	5.5	4	0.1	77
Santa Fe 05-12-88	1	2.5	4.9	20
	2	2.8	3.6	33
	3	3.0	3.3	--
	4	4.0	1.4	43
	4.2	4.0	---	--
Santa Fe 05-27-88	Surface	6.0	6.4	16
	1	5.5	6.5	16
	2	5.0	6.4	15
	3	5.0	6.4	15
	4	5.0	6.1	18
	5	4.8	3.2	20

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/1	Conductivity* $\mu S/cm^2$
Santa Fe				
06-14-88	Surface	12	6.8	20
	1	12	6.7	20
	2	12	6.75	20
	3	11.5	6.65	20
	4	10	7.0	20
	5	9	7.05	21
	6	8.5	6.5	28
Spirit				
06-04-86	Surface	8	7.6	28
	1	7	9.2	29
	2	7	9.2	29
	3	6.5	8.4	30
	4	6.0	8.2	31
Stewart				
06-02-86	Surface	7.0	8.2	36
	2	5.0	2.8	38
	4	4.9	1.8	39
	6	4.8	1.4	43
	8	4.7	1.3	43
	10	4.7	1.2	47
Lower Truchas				
07-10-87	Shoreline	15.5	——	18
	Surface	14.8	6.9	16
	1	14.8	6.9	16
	2	14.5	6.8	16
	3	14.2	7.1	22
Upper Truchas				
06-25-88	Surface	6.5	8.3	7
	1	6.3	——	7
	2	5.5	——	8
Horseshoe				
07-17-86	Surface	8.5	——	133
	1	7.8	——	140
	2	7.5	——	141
	3	7.8	——	150

Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/l	Conductivity* $\mu S/cm^2$
Horseshoe 07-18-87	Surface	8.0	8.3	136
	1	7.9	8.0	135
	2	7.5	8.0	137
	2.3	7.5	—	137
Lost 07-18-86	Surface	10	—	95
	1	10.2	—	95
	2	9.9	—	93
	3	10.0	—	92
	4	10.0	—	92
	5	9.8	—	94
	5.5	9.5	—	45
Lost 07-19-87	Surface	10.7	7.5	94
	1	10.2	7.2	95
	2	10	7.0	98
	3	9.8	7.0	98
	4	9.8	—	99
	5	9.6	7.1	103
Middle Fork 07-15-86	Surface	17	6.4	104
	1	16	8.0	107
	2	16	4.0	107
	3	15.5	4.5	108
	4	16	5.0	117
Middle Fork 10-08-87	Surface	9	7.4	121
	1	8.8	7.5	125
	2	8.8	7.4	123
	3	8.8	7.4	123
	3.5	9.0	—	146

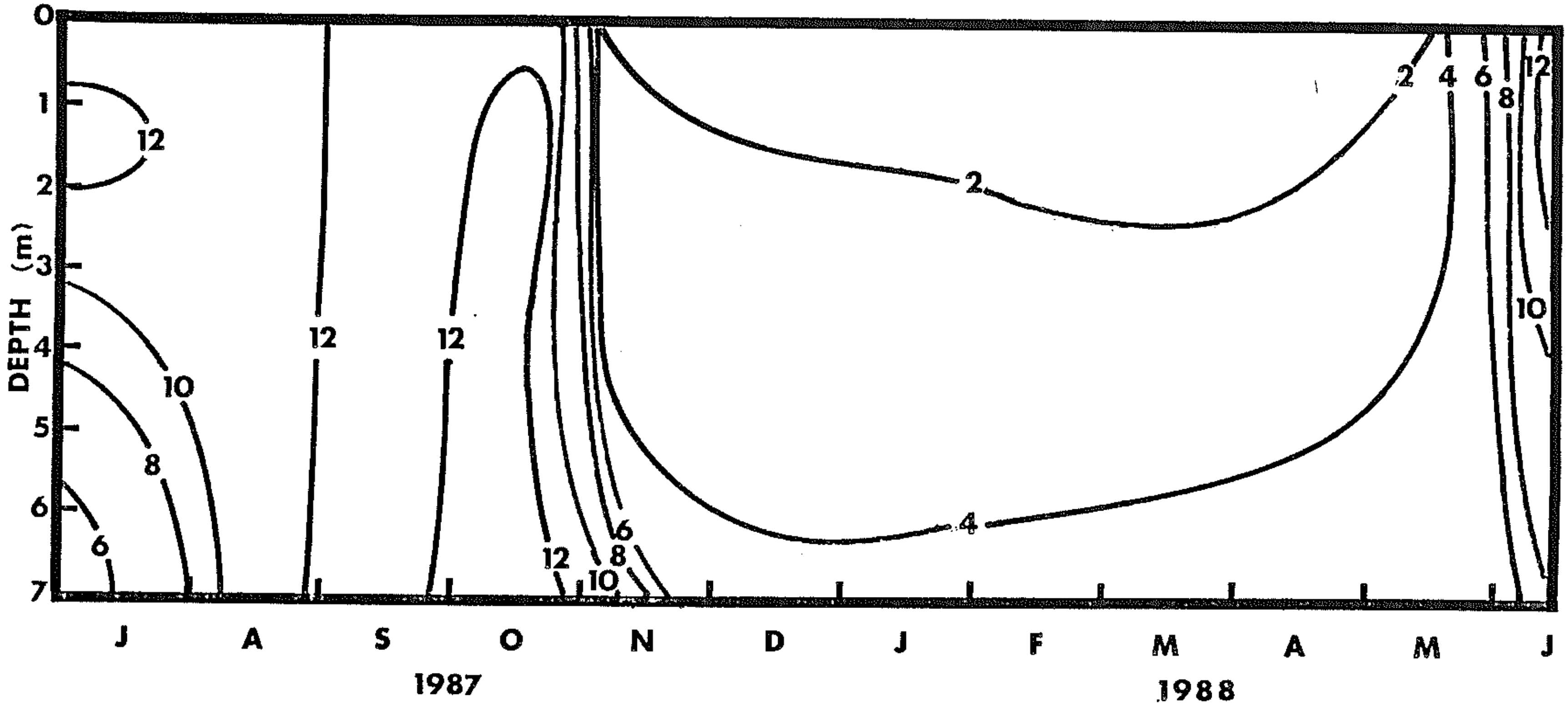
Appendix A (Continued)

Lake/Date	Depth m	Temp. °C	Dissolved Oxygen mg/l	Conductivity* $\mu S/cm^2$
Williams				
07-19-86	Surface	8	—	95
	1	8	—	95
	2	6.5	—	104
	2.2	6.5	—	118

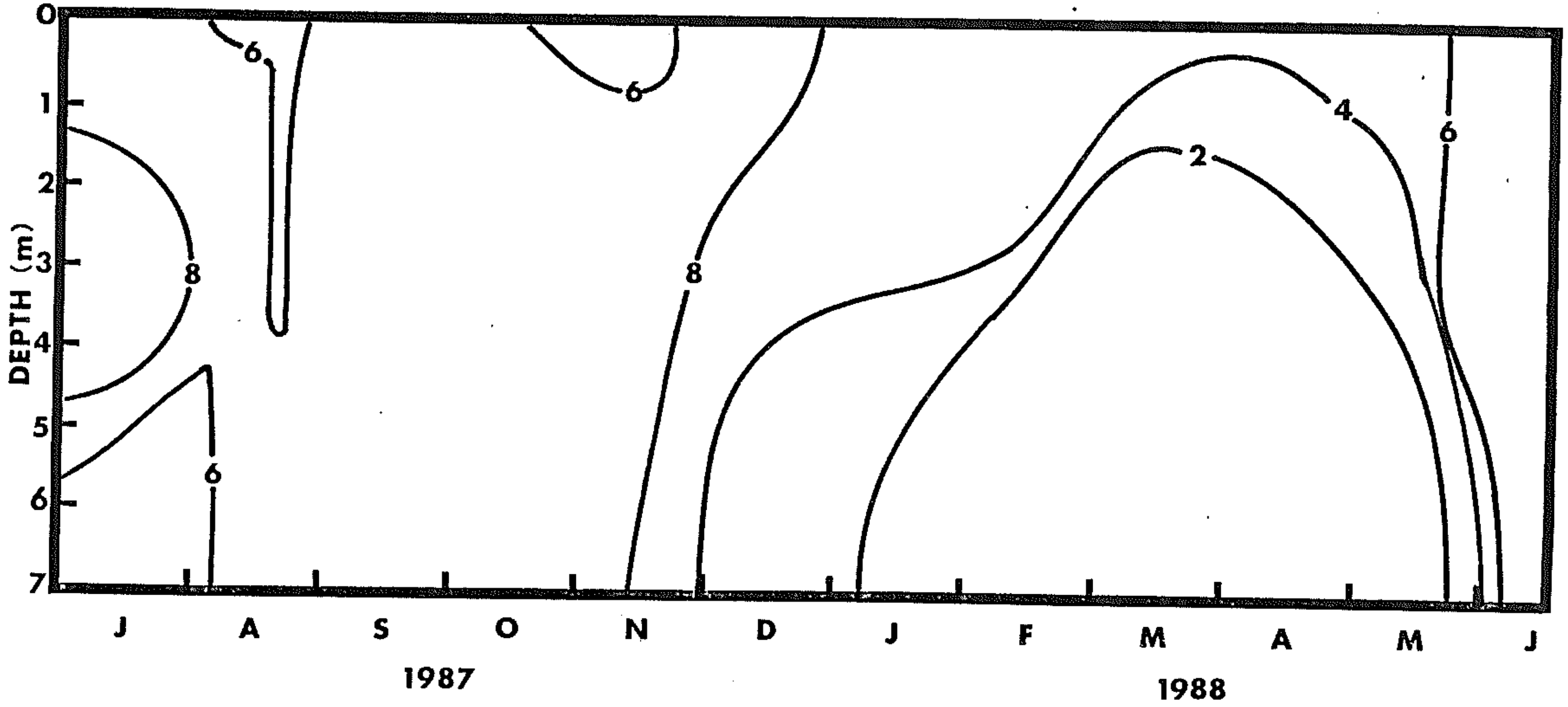
* corrected to 25°C

Appendix B. Isopleths for Temperature, Dissolved Oxygen, and Conductivity for Santa Fe Lake, July 1987 - June 1988

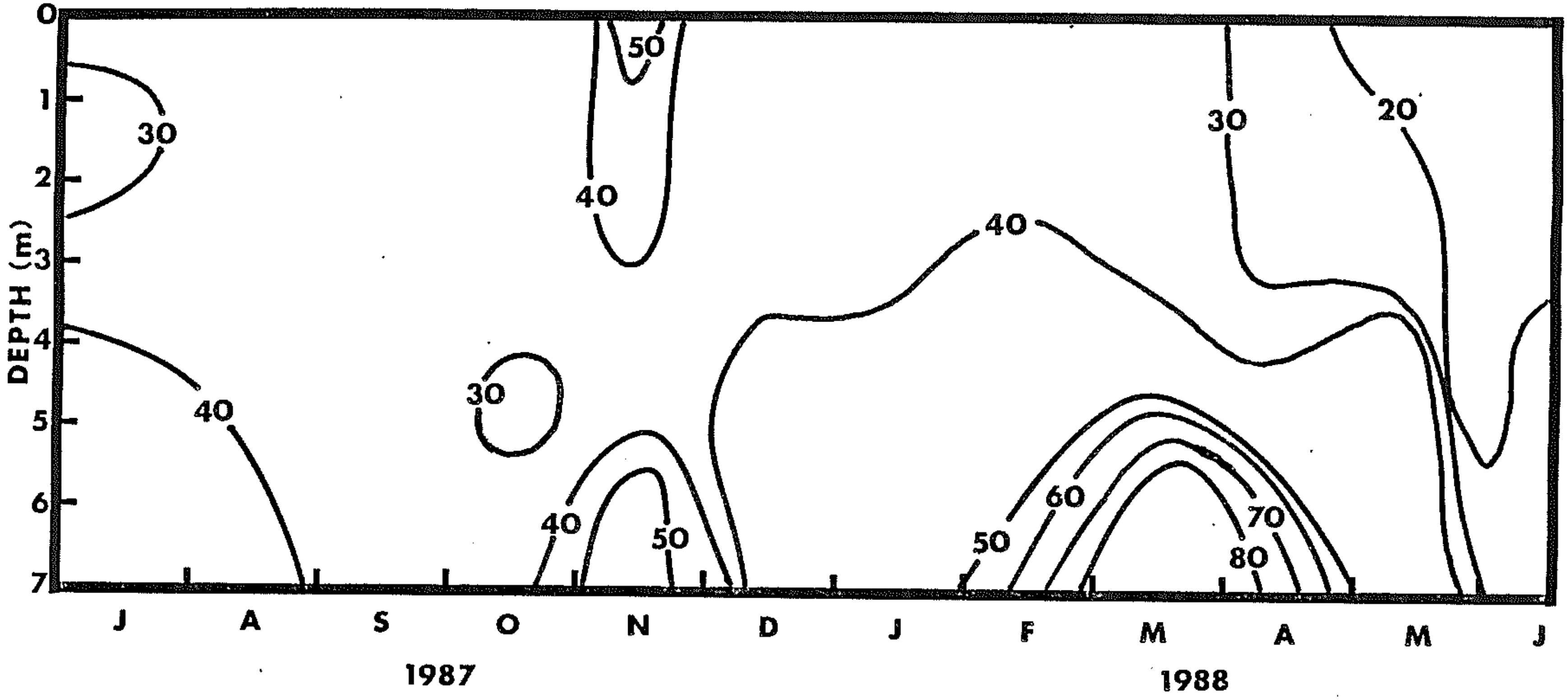
Appendix B-1. Isotherms for Santa Fe Lake, July 1987 to June 1988



Appendix B-2. Dissolved Oxygen Isopleth for Santa Fe Lake, July 1987 to June 1988



Appendix B-3. Conductivity Isopleth for Santa Fe Lake, July 1987 to June 1988



Appendix C. Summary of Lake Water Chemistry

Appendix C-1. Summary of Ion Chemistry

Lake	Date	pH	Alk µeq/l	SO_4^{2-} ppm	NO_3^- ppm	Cl^- ppm	Ca^{2+} ppm	Mg^{2+} ppm	Na^+ ppm	K^+ ppm	Sum Cat meq/l	Sum An meq/l
CLC Pond	06-21-87	7.45	500	2.92	0.02	0.31	7.70	1.21	2.84	0.79	0.630	0.570
Hidden	06-20-87	6.88	176	1.86	0.16	2.15	0.53	0.94	1.47	0.97	0.194	0.278
Hidden	07-05-88	6.40	296	1.72	1.72	1.38	3.30	1.20	1.50	1.20	0.361	0.398
Lagunitas #3	06-23-87	8.26	819	2.41	0.08	0.17	14.00	1.73	1.55	0.60	0.927	0.875
Sugarloaf	06-22-87	8.50	483	1.93	0.47	0.31	4.36	1.70	1.32	0.57	0.432	0.540
Sugarloaf	07-05-88	6.94	388	1.97	0.76	0.23	7.20	2.80	2.70	1.00	0.736	0.448
Johnson	07-08-87	6.38	162	2.67	0.04	0.13	2.00	0.49	0.96	0.40	0.193	0.222
Katherine	08-19-86	7.20	135	2.80	0.25	0.37	1.75	0.32	0.80	0.35	0.158	0.208
Katherine	07-07-87	6.86	131	1.41	0.25	0.17	1.90	0.35	0.48	0.44	0.156	0.169
Nambe	07-26-86	6.81	189	1.47	0.98	0.28	2.21	0.30	0.76	0.20	0.174	0.243
Pecos Baldy	08-17-86	8.34	868	4.40	0.34	0.39	15.18	0.96	0.23	0.31	0.857	0.976
Pecos Baldy	07-11-87	7.70	1037	5.90	0.44	0.15	19.00	1.30	0.12	0.25	1.070	1.171
Santa Fe	05-25-86	5.90	106	2.59	2.13	0.46	2.88	0.56	3.85	0.30	0.366	0.207
Santa Fe	07-01-87	6.92	154	2.49	0.02	0.16	2.35	0.64	0.99	0.42	0.225	0.211
Santa Fe	08-11-87	6.56	167	2.30	0.01	0.16	2.45	0.69	1.70	0.44	0.265	0.220
Santa Fe	09-03-87	5.86	202	2.38	0.23	0.60	2.50	0.65	2.75	0.74	0.318	0.272
Santa Fe	10-16-87	5.95	133	2.32	0.01	0.24	2.85	0.82	1.45	0.43	0.285	0.188
Santa Fe	11-12-87	7.15	122	2.60	0.02	0.27	2.40	0.78	1.90	0.33	0.276	0.184
Santa Fe	12-16-87	7.03	186	2.52	0.18	0.37	2.40	0.84	1.90	0.30	0.280	0.252
Santa Fe	02-11-88	6.89	166	0.80	1.50	0.57	2.40	0.75	1.40	0.25	0.250	0.223
Santa Fe	03-17-88	6.10	137	1.91	1.15	0.72	1.73	0.60	1.29	0.40	0.203	0.216
Santa Fe	04-17-88	5.69	173	2.36	1.16	0.37	2.09	0.76	1.31	0.39	0.235	0.251
Santa Fe	05-12-88	5.68	197	1.46	0.44	0.90	1.90	0.34	0.93	0.30	0.171	0.260
Santa Fe	05-27-88	5.97	119	1.97	1.29	0.34	2.40	0.65	1.00	0.45	0.229	0.190
Santa Fe Outlet	05-27-88	6.54	107	1.86	0.40	0.56	2.20	0.56	1.10	0.40	0.215	0.168
Santa Fe	06-14-88	6.11	124	1.87	0.01	0.20	2.12	0.49	1.54	0.39	0.224	0.169

Appendix C-1 (continued)

Lake	Date	pH	Alk µeq/1	SO_4^{2-} ppm	NO_3^- ppm	Cl^- ppm	Ca^{2+} ppm	Mg^{2+} ppm	Na^+ ppm	K^+ ppm	Sum Cat meq/1	Sum An meq/1
Spirit	06-04-86	7.40	247	3.89	1.49	0.70	3.17	0.86	1.43	0.47	0.304	0.372
Spirit	07-07-87	6.88	246	3.90	0.18	0.25	2.90	1.08	2.10	0.41	0.337	0.337
Spirit	06-21-88	6.77	208	11.67	6.19	0.60	10.26	0.98	2.07	0.49	0.697	0.568
Stewart	06-02-86	6.90	204	2.69	0.46	0.51	3.43	0.60	1.39	0.75	0.301	0.282
Stewart	07-09-87	6.50	187	2.88	0.01	0.24	1.50	0.57	2.80	0.36	0.253	0.254
Stewart	06-21-88	6.80	143	2.93	0.94	0.19	2.77	0.56	2.26	0.47	0.295	0.225
Stewart Bog	07-09-87	5.95	230	0.68	0.25	0.17	2.70	0.87	2.80	0.52	0.343	0.253
Truchas	07-10-87	5.49	8	0.86	0.04	0.11	0.67	0.19	0.42	0.17	0.072	0.030
Truchas	06-25-88	5.36	13	0.96	0.09	0.27	0.66	0.12	0.27	0.22	0.060	0.042
Truchas (Upper)	06-25-88	5.08	6	1.09	1.71	1.39	0.64	0.12	0.27	0.24	0.060	0.095
Horseshoe	07-17-86	8.40	831	22.11	1.18	0.26	19.05	1.36	0.61	0.50	1.105	1.318
Horseshoe	07-18-87	7.85	961	19.50	0.62	0.21	21.00	1.40	0.80	0.38	1.211	1.383
Lost	07-18-86	8.40	586	8.67	0.90	0.23	10.73	1.44	0.35	0.61	0.687	0.788
Lost	07-19-87	7.74	841	9.49	0.83	0.32	14.40	1.80	0.51	0.39	0.902	1.061
Middle Fork	07-15-86	8.60	1030	0.92	ND	0.17	0.33	0.04	0.15	0.10	0.029	1.054
Middle Fork	10-08-87	7.69	1170	2.92	0.16	0.22	25.00	2.81	1.40	0.86	1.567	1.240
Williams	07-19-86	7.55	432	16.49	0.41	3.31	13.11	0.73	0.99	4.06	0.863	0.875
Williams	07-20-87	7.47	630	18.00	ND	0.47	17.00	1.00	0.93	0.46	0.986	1.018

ND = Not Determined

Appendix C-2. Summary of Lake Chemical Characteristics

Lake	Date	Secchi m	TDS mg/1	CHL a µg/1	TOC ppm	SiO_2 ppm
CLC Pond	06-21-87	VTB	18	5.0	3.40	6.49
Hidden	06-20-87	2.5	23	6.1	2.25	4.21
Hidden	07-05-88	ND	ND	ND	ND	ND
Lagunitas #3	06-23-87	1.3	36	6.2	3.63	5.00
Sugarloaf	06-22-87	1.0	29	9.7	6.70	3.79
Sugarloaf	07-05-88	ND	ND	ND	6.60	ND
Johnson	07-08-87	4.5	13	3.5	3.13	2.22
Katherine	08-19-86	6.0	42	184.1	1.30	ND
Katherine	07-07-87	5.0	3	3.5	ND	0.84
Nambe	07-26-86	VTB	42	58.7	1.10	ND
Pecos Baldy	08-17-86	3.2	103	BDL	ND	ND
Pecos Baldy	07-11-87	ND	43	5.2	1.95	0.16
Santa Fe	05-25-86	3.8	44	7.2	2.16	ND
Santa Fe	07-01-87	3.3	18	BDL	1.84	2.21
Santa Fe	08-11-87	ND	21	ND	3.95	2.18
Santa Fe	09-03-87	3.9	24	4.7	4.13	ND
Santa Fe	10-16-87	4.0	21	BDL	4.50	1.82
Santa Fe	11-12-87	ND	21	BDL	0.90	1.82
Santa Fe	12-16-87	ND	20	3.5	1.10	2.18
Santa Fe	02-11-88	ND	ND	ND	0.80	1.82
Santa Fe	03-17-88	ND	ND	ND	ND	ND
Santa Fe	04-17-88	ND	ND	ND	0.70	ND
Santa Fe	05-12-88	ND	ND	ND	0.60	ND
Santa Fe	05-27-88	2.7	ND	ND	ND	ND
Santa Fe Outlet	05-27-88	ND	ND	ND	ND	ND
Santa Fe	06-14-88	6.0	ND	ND	ND	ND

Appendix C-2 (continued)

Lake	Date	Secchi m	TDS mg/1	CHL a µg/1	TOC ppm	SiO_2 ppm
Spirit	06-04-86	VTB	24	5.8	1.30	ND
Spirit	07-07-87	ND	4	5.2	2.83	1.22
Spirit	06-21-88	ND	ND	ND	1.20	ND
Stewart	06-02-86	4.2	ND	ND	1.10	ND
Stewart	07-09-87	ND	4	BDL	2.12	3.36
Stewart	06-21-88	ND	ND	ND	0.90	ND
Stewart Bog	07-09-87	ND	ND	ND	16.20	ND
Truchas	07-10-87	2.7	6	BDL	1.88	0.49
Truchas	06-25-88	ND	ND	ND	5.10	ND
Truchas (Upper)	06-25-88	VTB	ND	ND	0.20	ND
Horseshoe	07-17-86	VTB	95	14.5	1.10	ND
Horseshoe	07-18-87	VTB	68	BDL	1.26	1.21
Lost	07-18-86	4.9	70	27.8	0.80	ND
Lost	07-19-87	4.7	49	BDL	2.08	1.09
Middle Fork	07-15-86	VTB	74	7.2	ND	ND
Middle Fork	10-08-87	ND	71	ND	7.50	0.36
Williams	07-19-86	VTB	73	4.8	ND	ND
Williams	07-20-87	ND	46	BDL	21.5	1.07

BDL = Below Detection Limit of 2.9 g/1
ND = Not Determined
VTB = Visible to Bottom

Appendix D. Precipitation Chemistry Summary

Appendix D. Precipitation Chemistry Summary

Site	Date	Sample Type*	pH	SO_4^{2-} ppm	NO_3^- ppm	Cl^- ppm	Ca^{2+} ppm	Mg^{2+} ppm	Na^+ ppm	K^+ ppm
Brazos Ridge	06-23-87	S	5.54	0.16	0.12	0.31	0.30	0.03	0.37	0.16
CLC Pond	06-21-87	S	6.48	1.38	0.28	0.36	3.90	0.14	0.19	0.23
Chama	03-13-88	S	4.81	1.12	2.15	0.29	ND	ND	ND	ND
Chama	05-30-88	S	4.83	1.44	0.93	0.55	1.20	0.23	0.52	0.22
Hidden Road	06-20-87	S	3.64	0.47	ND	0.83	0.60	0.08	0.67	0.62
Hidden	06-20-87	S	3.90	1.16	2.03	0.50	0.42	0.55	0.77	0.55
Lagunitas #3	06-23-87	S	5.56	0.42	0.24	3.54	1.10	0.13	3.10	1.60
Katherine	07-07-87	S	4.84	1.21	0.26	1.30	0.56	0.12	1.50	0.64
Lake Peak	04-25-86	S	4.87	0.55	0.05	0.36	0.10	0.03	0.41	0.05
Lake Peak	07-01-87	S	4.95	0.29	0.06	0.15	0.30	0.02	0.10	0.10
Pecos Baldy	07-11-87	S	4.55	0.40	0.04	0.43	0.30	0.07	0.60	0.27
Santa Fe	05-25-86	S	5.41	2.40	1.85	ND	1.74	0.16	2.14	2.75
Santa Fe	07-01-87	S	4.95	0.38	0.23	0.57	1.18	0.30	0.73	0.52
Santa Fe	10-14-87	S	4.20	0.55	0.01	0.36	0.40	0.05	0.40	0.19
Santa Fe	09-03/10-13-87	R	5.35	3.72	1.22	1.29	0.25	2.20	1.70	0.66
Santa Fe	11-11-87	S	5.73	1.52	1.22	0.39	1.25	0.24	1.95	0.10
Santa Fe	10-15/11-11-87	R	5.39	1.14	0.49	0.28	0.49	0.15	0.58	0.17
Santa Fe	12-16-87	S	4.76	0.39	0.53	0.66	0.58	0.06	0.21	0.16
Santa Fe	01-07-88	S	5.37	0.98	0.83	0.50	0.50	0.03	0.10	0.10
		Top 1'	5.22	0.82	3.77	2.04	1.09	0.09	2.50	0.45
		Bot 1'	4.65	0.95	2.67	1.36	0.80	0.10	0.51	0.27
Santa Fe	02-11-88	Top 2"	5.85	1.01	0.86	0.15	2.60	0.11	0.13	0.97
		0"-12"	4.91	0.76	0.32	0.59	0.50	0.03	0.24	0.10
		12"-24"	4.28	0.80	1.50	0.57	0.10	0.03	0.17	0.11
		24"-36"	4.15	0.38	0.26	0.59	0.50	0.03	0.08	0.10
		36"-48"	4.34	0.64	0.49	0.35	0.50	0.03	0.08	0.12
		48"-60"	4.25	0.32	0.38	0.37	0.50	0.02	0.09	0.10
		60"-72"	4.26	0.84	0.59	0.31	0.55	0.03	0.24	0.11
Santa Fe	03-17-88	Top 6"	5.33	1.11	1.64	0.78	0.86	0.05	0.30	0.12
		0"-12"	4.93	0.75	1.17	0.92	1.03	0.15	0.59	2.50

Appendix D (continued)

Site	Date	Sample Type	pH	SO_4^{2-} ppm	NO_3^- ppm	Cl^- ppm	Ca^{2+} ppm	Mg^{2+} ppm	Na^+ ppm	K^+ ppm
Santa Fe	03-17-88	12"-24"	4.47	0.92	0.46	1.07	0.42	0.03	0.22	0.12
		24"-36"	4.55	0.59	0.58	1.14	0.50	0.02	0.18	0.12
		36"-48"	4.39	0.50	0.41	0.58	0.50	0.02	0.20	0.08
		48"-60"	4.98	0.48	0.64	0.73	0.42	0.03	0.27	0.20
		60"-72"	4.45	2.24	1.20	2.90	1.12	0.14	0.78	0.13
Santa Fe	04-17-88	0"-12"	5.12	0.38	0.29	0.62	0.50	0.03	0.20	0.07
		12"-24"	5.15	0.80	0.42	0.31	0.53	0.04	0.47	0.10
		24"-36"	4.05	0.53	0.43	0.42	0.50	0.03	0.20	0.10
		36"-48"	4.15	0.42	0.38	0.53	0.50	0.03	0.20	0.09
		48"-60"	4.62	0.55	1.26	0.24	0.50	0.04	0.20	0.07
Santa Fe	05-12-88	S	6.11	0.56	0.30	0.38	1.10	0.19	0.15	0.67
		0"-12"	4.87	0.24	0.29	0.36	0.25	0.04	0.40	0.13
		12"-24"	4.79	0.23	0.32	0.29	0.25	0.03	0.19	0.11
		24"-36"	4.94	0.51	0.32	0.53	0.15	0.03	0.16	0.10
Santa Fe	05-27-88	"fresh" snow	6.84	0.89	0.63	0.24	1.10	0.14	0.21	0.20
		0"-12"	6.05	0.91	0.71	0.17	1.70	0.23	0.95	1.30
		12"-24"	5.85	0.73	0.55	0.40	1.50	0.25	0.76	0.50
Santa Fe	06-14-88	S	4.50	0.25	0.23	0.31	0.19	0.03	0.15	0.16
Stewart	06-02-86	S	4.74	2.69	0.46	0.49	0.48	0.07	0.40	0.18
Truchas	07-10-87	S	5.30	0.51	0.02	0.43	0.03	0.06	0.64	0.24
Truchas	06-24-88	S	4.45	0.22	0.06	0.06	0.11	ND	0.05	0.09
Horseshoe	07-18-87	S	6.70	0.32	0.13	0.43	0.30	0.10	0.33	0.10
Lost	07-18-86	S	4.60	4.18	0.07	0.67	ND	ND	ND	ND
Lost	07-19-87	S	4.48	0.76	0.03	0.38	0.31	0.05	0.42	0.29
Taos Ski Valley	02-28-88	S	4.63	0.99	0.57	0.56	ND	ND	ND	ND

*S = Snow
R = Rain
ND = Not Determined

Appendix E. Metal Analysis Data for Sediments (All lakes were sampled in 1987, except where otherwise noted.)

Appendix E-1. Trace Metal Concentrations (ppm dry weight) in Core Sections of Lake Sediments

Sample	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn
CLC Pond-1	12600	23	40	14110	.243	238	16	100	36	61
CLC Pond-5	53100	20	42	22100	.060	301	14	105	40	67
CLC Pond-8	47600	41	42	20800	.184	370	17	114	42	77
Hidden-1	34220	21	47	15190	7.15	405	18	57	31	56
Hidden-3	49320	19	37	15720	.125	394	20	52	29	55
Hidden-5	54100	21	34	14130	.172	373	21	28	26	47
Hidden-1*	20370	22	52	24980	.242	670	16	44	34	60
Hidden-5	25020	27	35	13030	.239	415	15	53	27	72
Hidden-8	21580	25	35	15010	.501	456	17	32	32	47
Lagunitas #3-3	6340	24	45	22890	.043	333	24	31	42	55
Lagunitas #3-9	14580	16	56	27150	.269	370	24	44	48	61
Lagunitas #3-15	40810	17	54	26080	.057	407	28	40	43	77
Lagunitas #3-25	12070	21	74	28030	.102	364	27	44	53	35
Lagunitas #3-32	54890	18	51	27190	.174	429	26	50	47	70
Lagunitas #32-2*	17650	18	69	27810	.438	690	34	58	51	71
Lagunitas #32-5	19710	24	59	31480	.187	640	30	38	45	76
Lagunitas #32-10	17910	19	63	31560	33.1	720	34	44	49	72
Lagunitas #32-15	16870	21	56	29130	.125	670	30	37	41	63
Lagunitas #32-18	26400	23	55	28870	.262	630	30	44	39	62
Sugarloaf-1	17730	47	71	30480	.339	1150	32	69	82	87
Sugarloaf-3	15600	45	63	29050	.635	1640	29	69	59	73
Sugarloaf-5	8870	40	30	29780	.114	877	26	75	58	103
Sugarloaf-7	16360	40	42	20270	.145	1140	23	66	41	43
Johnson-1	41330	15	53	11090	.212	147	12	51	26	49
Johnson-5	44630	17	56	13010	.211	187	11	53	32	57
Johnson-9	23770	14	58	13050	.341	168	13	52	31	44
Johnson-1*	37810	38	66	12920	.223	378	20	73	31	73
Johnson-4	47770	21	53	11850	.697	303	10	41	22	57
Johnson-7	30230	18	76	14330	.190	397	12	52	30	73
Johnson-10	52180	21	68	13980	.206	372	13	42	32	65
Johnson-14	38950	11	66	11830	.197	334	15	41	24	49
Katherine-1	51510	21	69	16610	.164	405	19	93	32	69
Katherine-5	56660	18	75	18750	.403	488	15	78	51	72
Katherine-10	44480	14	74	21390	.218	446	16	70	34	69
Katherine-15	39750	19	76	24200	.289	510	17	81	39	80
Katherine-20	28580	10	30	19930	.145	530	12	70	24	57

---

* Denotes another core analyzed

Appendix E-1 (Continued)

Sample	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn
Nambe-3, 1986	32830	20	105	10750	.006	311	11	180	24	46
Nambe-9	57160	20	95	12280	.003	303	13	88	28	55
Nambe-14	54990	26	118	11870	.118	355	12	63	27	49
Nambe-22	40530	8	107	1150	.004	345	8	56	26	50
Nambe-30	16080	9	143	10080	.003	339	5	49	24	43
Pecos Baldy-4, 1986	51090	42	17	20080	.026	326	15	78	42	101
Pecos Baldy-7	33340	35	12	14180	.018	244	14	40	32	92
Pecos Baldy-10	35000	32	11	14050	.052	231	17	54	36	76
Pecos Baldy-16	42250	56	13	17790	77.7	227	19	48	36	81
Pecos Baldy-22	62050	41	13	17200	.218	208	26	31	89	76
Santa Fe-2	42040	25	149	17720	4.39	319	22	93	32	143
Santa Fe-5	14320	26	71	17370	.115	715	11	100	30	133
Santa Fe-9	37760	36	126	13450	.179	311	21	81	31	71
Santa Fe-12	9440	14	54	11650	.044	77	3	58	22	63
Santa Fe-14	36330	23	108	12560	.349	294	14	83	28	56
Santa Fe-17	22610	23	113	14220	.169	341	16	73	29	57
Santa Fe-18	30570	25	112	13920	.219	312	18	68	28	55
Spirit-11, 1986	25400	24	31	8910	.110	329	12	85	27	55
Spirit-17	22700	8	26	9090	.019	339	11	112	23	42
Spirit-22	34560	6	25	9060	.027	320	9	99	26	49
Spirit-29	46160	5	28	10320	.526	332	13	101	35	45
Spirit-33	12890	6	25	11580	.045	329	10	78	39	51
Stewart-2, 1986	31520	13	10	15600	.081	383	4	62	29	62
Stewart-5	36910	19	15	17230	.262	436	11	63	32	44
Stewart-8	40700	4	12	19560	.085	473	10	84	45	51
Stewart-11	23120	27	8	13970	.097	472	11	70	47	39
Stewart-14	45000	18	6	12770	.032	404	22	62	41	4
Stewart-1*	47240	17	58	20630	.174	600	22	98	32	86
Stewart-4	4950	12	27	22500	.054	310	7	75	31	86
Stewart-7	68150	14	55	25510	.066	660	20	114	34	91
Stewart-8	25250	33	24	24130	.067	380	8	85	28	90
Stewart-10	21590	17	64	28120	.141	660	17	88	33	78
Stewart-13	33830	12	32	15250	.302	520	17	55	20	58
Stewart-14	76350	54	38	23500	.324	990	19	67	28	69
Truchas-1	51060	28	43	22770	.074	150	20	94	36	67
Truchas-5	6160	30	25	15220	1.2	131	67	94	28	60
Truchas-8	59140	22	15	18560	.072	139	13	69	26	85
Truchas-10	5950	17	30	15860	.245	141	16	66	31	63
Truchas-13	51550	29	14	16520	.091	136	12	63	20	81
Truchas-15	63420	31	27	14030	.156	136	20	55	32	58
Truchas-21	24730	12	15	7950	.093	72	18	53	14	31

---

* Denotes another core analyzed

Appendix E-1 (Continued)

Sample	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn
Horseshoe-4, 1986	56380	44	39	23650	.039	341	19	70	50	92
Horseshoe-10	42500	35	43	22810	.045	333	21	74	61	110
Horseshoe-18	36340	22	36	18840	.037	276	14	72	48	73
Horseshoe-27	50370	25	45	19690	1.81	277	17	65	48	92
Horseshoe-33	53340	38	50	33380	.088	434	32	94	69	117
Lost Lake-1	9660	41	92	25920	.224	499	16	75	50	92
Lost Lake-4	11300	59	114	34810	.268	494	27	85	70	12
Lost Lake-8	4810	76	40	28950	.176	254	18	69	60	129
Lost Lake-9	11230	49	100	28750	.502	401	24	69	61	102
Lost Lake-12	14760	45	96	32250	.215	427	33	65	61	106
Lost Lake-15	13100	36	91	27270	.279	407	27	82	57	103
Middle Fork-2, 1986	27360	27	70	17500	.028	347	14	189	41	55
Middle Fork-13	39700	30	90	17500	.020	308	17	87	45	51
Middle Fork-20	20040	31	109	17130	.665	307	16	85	56	71
Middle Fork-30	22170	21	80	15430	.035	316	14	104	37	52
Middle Fork-39	29230	28	88	18650	.037	351	17	119	42	64
Williams-2, 1986	53750	24	201	32060	.076	446	16	230	60	579
Williams-10	24670	32	192	30610	.040	457	24	196	69	476
Williams-17	36110	26	191	29050	.058	428	24	224	59	554
Williams-25	35160	23	157	25470	.120	406	24	206	55	490
Williams-35	55530	25	187	27010	1.57	411	27	375	57	539

Appendix E-2. Major Metal Concentrations (ppm dry weight) in Core Sections of Lake Sediments

Sample	Ca	K	Mg	Na
CLC Pond-1	5993	8062	1792	5140
CLC Pond-5	6726	13620	6191	6993
CLC Pond-8	8232	13458	5830	7003
Hidden-1	6855	8059	4443	9412
Hidden-3	7433	9756	5984	9875
Hidden-5	7290	13182	6894	7790
Hidden-1*	7647	9065	2207	9749
Hidden-5	6931	9576	4371	8741
Hidden-8	8637	8327	3599	11017
Lagunitas #3-3	4725	5256	830	2674
Lagunitas #3-9	5923	7306	1289	3517
Lagunitas #3-15	7291	10920	5398	2075
Lagunitas #3-25	6592	12281	2317	9249
Lagunitas #3-32	6776	11979	6384	8260
Lagunitas #32-2*	6937	11683	694	5388
Lagunitas #32-5	7166	9876	1471	5584
Lagunitas #32-10	8301	10360	2956	10873
Lagunitas #32-15	5721	10705	1191	4404
Lagunitas #32-18	4883	11005	2903	3737
Sugarloaf-1	8238	18310	909	14460
Sugarloaf-3	8596	19050	494	14660
Sugarloaf-5	4600	17945	100	15500
Sugarloaf-7	5518	10197	596	10036
Johnson-1	4286	9312	3123	6779
Johnson-5	5155	7993	3099	5584
Johnson-9	4130	8676	1615	6464
Johnson-1*	4640	9153	2797	8607
Johnson-4	4562	9407	3114	8719
Johnson-7	4997	8406	1422	8920
Johnson-10	5175	7569	1622	10588
Johnson-14	4042	7403	2874	9008
Katherine-1	4577	11669	3704	11008
Katherine-5	4541	10679	4509	11535
Katherine-10	4533	11907	3257	8676
Katherine-15	3646	20080	3286	10640
Katherine-20	5246	23050	2601	12790

* Denotes another core analyzed

Appendix E-2 (Continued)

Sample	Ca	K	Mg	Na
Nambe-3, 1986	5226	10228	2098	8151
Nambe-9	6849	13206	4613	11519
Nambe-14	7464	14930	4431	13548
Nambe-22	5215	12554	2717	11133
Nambe-30	4147	8754	1236	8453
Pecos Baldy-4, 1986	6159	10613	3480	10287
Pecos Baldy-7	4658	8791	3889	7138
Pecos Baldy-10	4033	10212	4858	7033
Pecos Baldy-16	4120	10437	5086	7652
Pecos Baldy-22	5334	11225	5529	7953
Santa Fe-2	4832	11184	4386	8816
Santa Fe-5	5700	9891	1500	7874
Santa Fe-9	4588	7617	4015	7680
Santa Fe-12	2200	6035	700	1117
Santa Fe-14	4063	9498	3681	8478
Santa Fe-17	4406	9116	2562	10944
Santa Fe-18	3166	8980	3199	8631
Spirit-11, 1986	5461	8631	1006	9994
Spirit-17	5840	9437	1027	10334
Spirit-22	5590	10388	2206	12816
Spirit-29	5330	10369	2720	11862
Spirit-33	4200	11296	1023	9478
Stewart-2, 1986	5134	12881	2892	11714
Stewart-5	5981	12412	2761	9950
Stewart-8	5434	10642	2522	9844
Stewart-11	2814	11560	2447	10438
Stewart-14	3484	14314	3503	13090
Stewart-1*	6819	12943	3222	11798
Stewart-4	3700	9451	100	9829
Stewart-7	5700	12870	3500	12064
Stewart-8	4300	9994	1300	12415
Stewart-10	5447	10632	1520	11714
Stewart-13	3752	6474	2709	6752
Stewart-14	7099	17880	4126	14660
Truchas-1	3857	1667	4700	510
Truchas-5	3525	15380	4599	6521
Truchas-8	1700	11445	100	10571
Truchas-10	3791	12757	3781	8104
Truchas-13	2000	11324	1300	10504
Truchas-15	4352	16500	4704	6744
Truchas-21	2422	7691	2641	3454

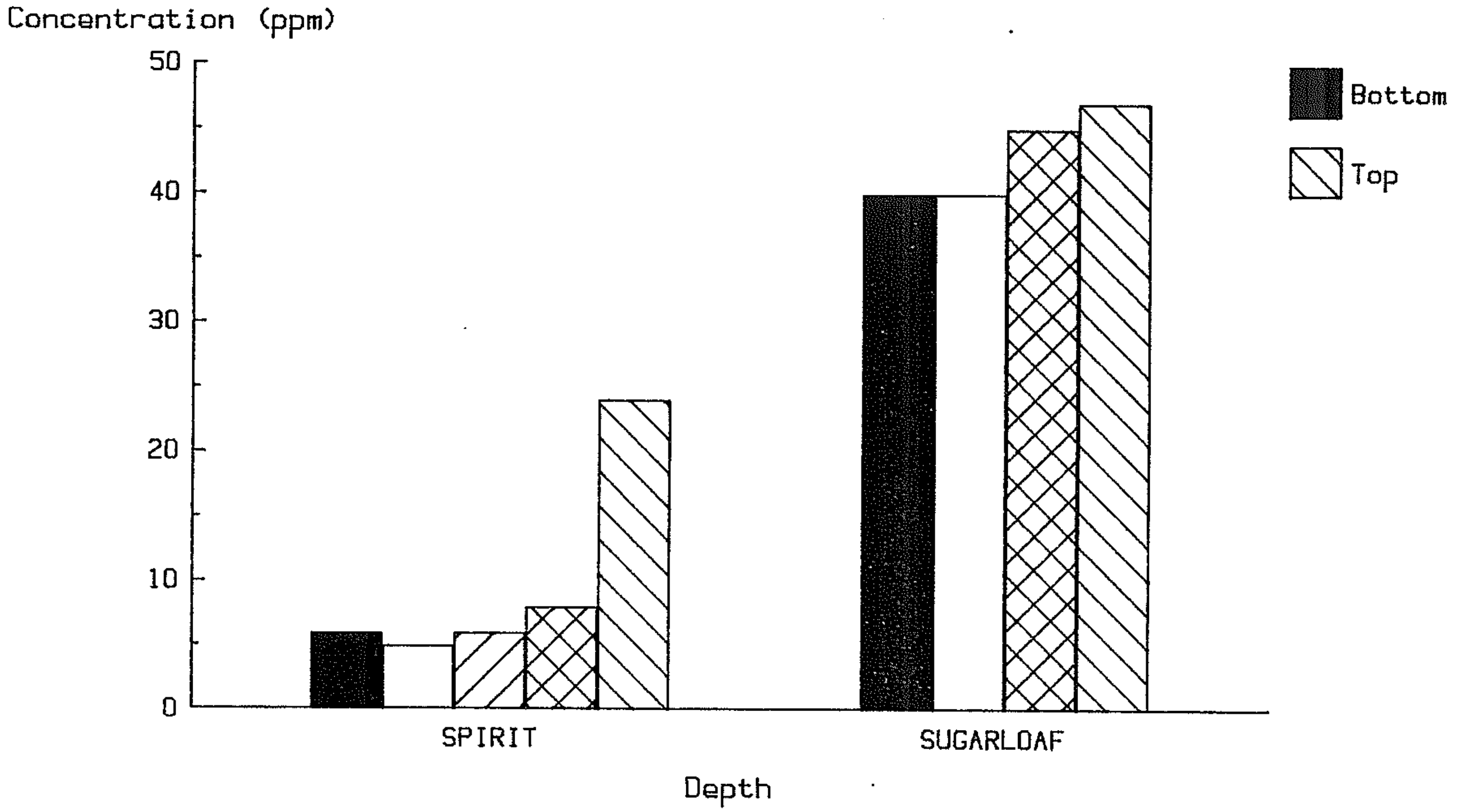
* Denotes another core analyzed

Appendix E-2 (Continued)

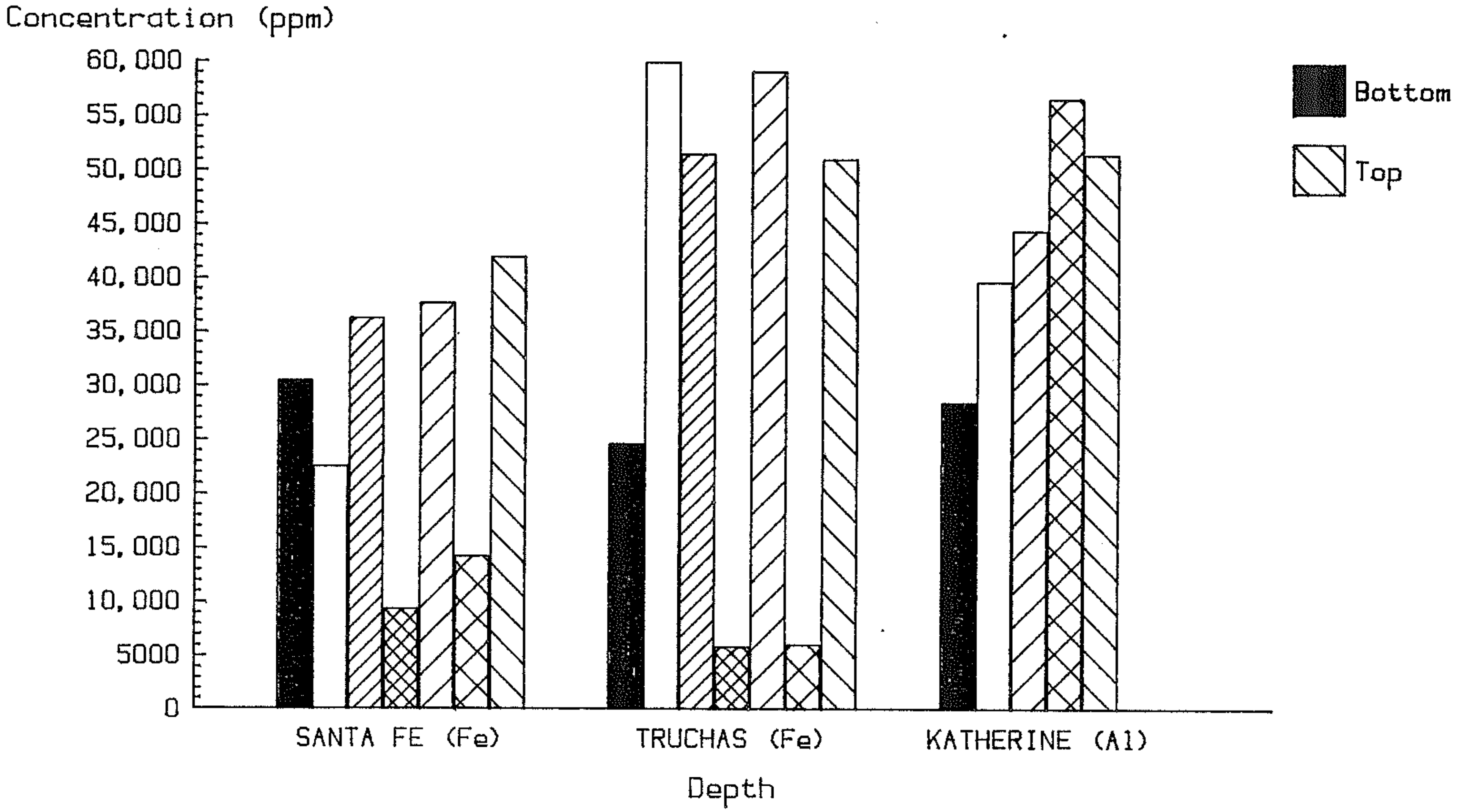
Sample	Ca	K	Mg	Na
Horseshoe-4, 1986	8568	16600	6134	9426
Horseshoe-10	6327	20890	5939	7470
Horseshoe-18	5423	11272	4368	7065
Horseshoe-27	7686	12993	6322	7661
Horseshoe-33	9308	21190	6407	15230
Lost Lake-1	5871	16310	1972	10188
Lost Lake-4	5609	19350	1406	9557
Lost Lake-8	3300	16030	100	4672
Lost Lake-9	4027	20530	344	6053
Lost Lake-12	5104	18120	1044	9131
Lost Lake-15	4995	19500	507	9092
Middle Fork-2, 1986	6971	8657	2456	9385
Middle Fork-13	6981	16280	5316	10710
Middle Fork-20	4454	10799	2512	6194
Middle Fork-30	6280	9506	2105	7607
Middle Fork-39	6994	10190	2674	10242
Williams-2, 1986	8711	17070	4752	10946
Williams-10	6217	12895	1701	7573
Williams-17	6884	13029	4175	9548
Williams-25	7069	10905	3843	8979
Williams-35	8191	12688	5476	10215

Appendix F. Trace Metal Trends in Lake Sediment Cores with Linear Regression (R) Values Correlated for $P < 0.1$

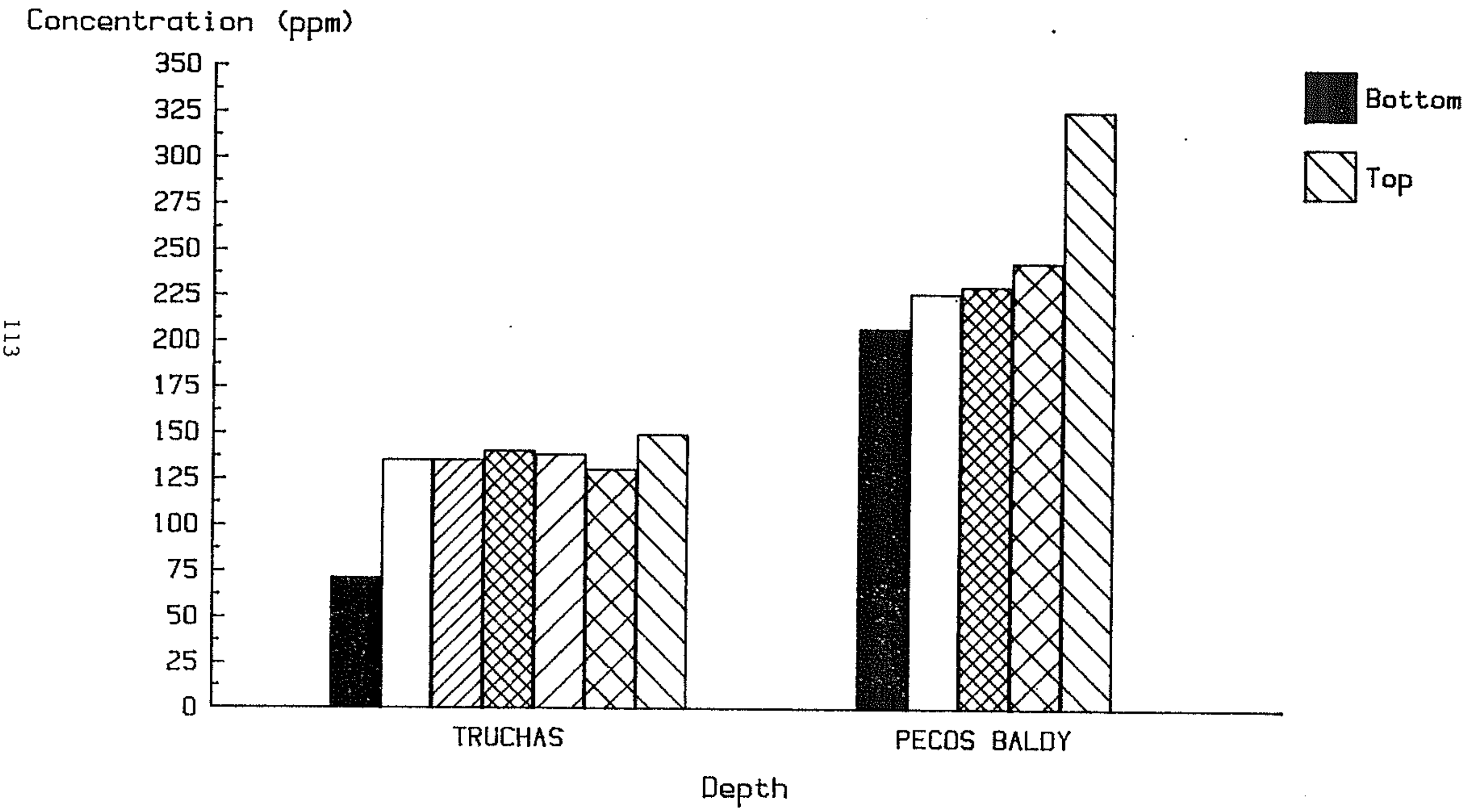
Appendix F-1. Concentrations of Cr in Sediment Core Sections of Spirit and Sugarloaf Lakes



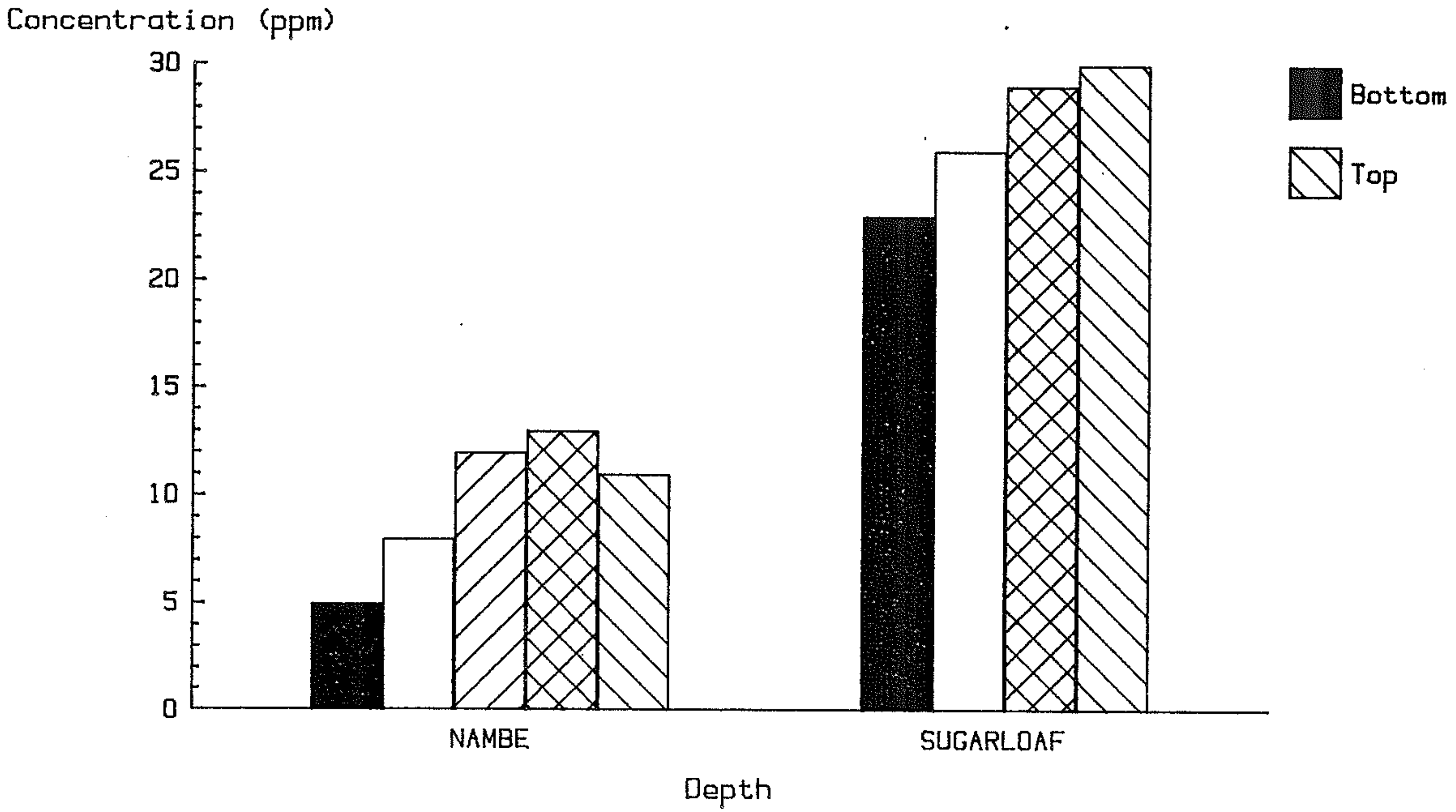
Appendix F-2. Concentrations of Fe in Sediment Core Sections of Santa Fe and Truchas Lakes and of Al in Lake Katherine



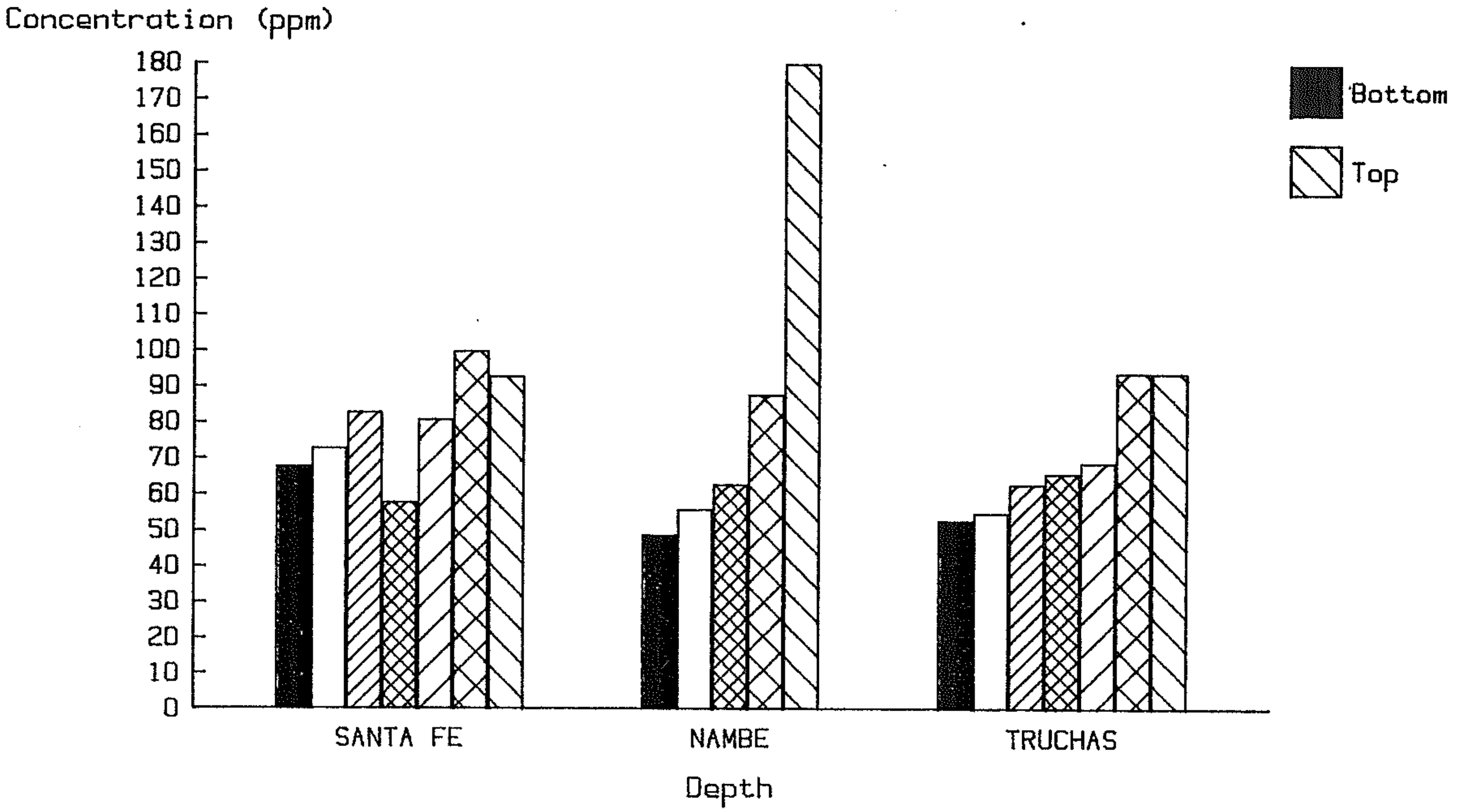
Appendix F-3. Concentrations of Mn in Sediment Core Sections of Truchas and Pecos Baldy Lakes



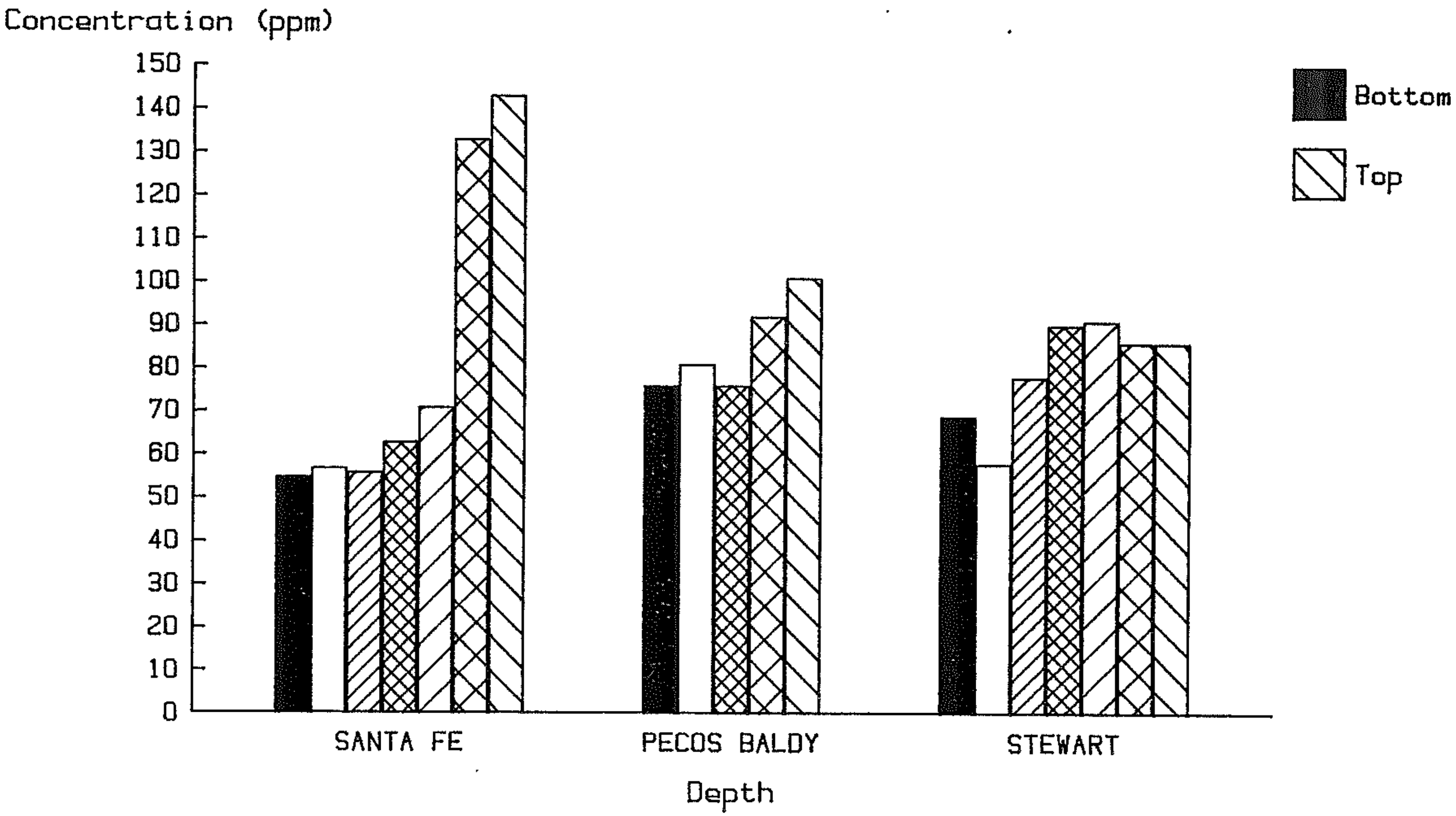
Appendix F-4. Concentrations of Ni in Sediment Core Sections of Nambe and Sugarloaf Lakes



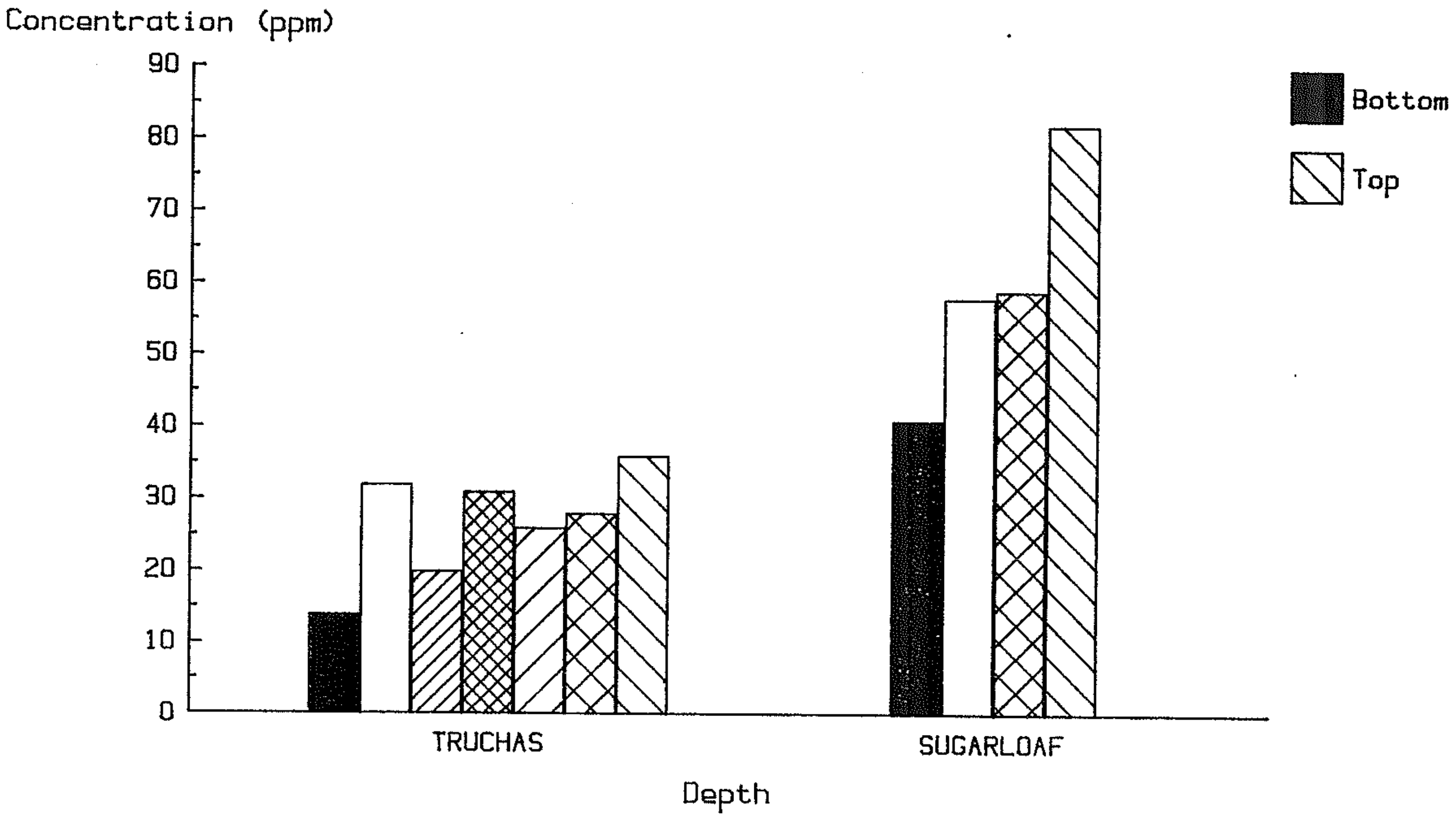
Appendix F-5. Concentrations of Pb in Sediment Core Sections of Santa Fe, Nambe, and Truchas Lakes



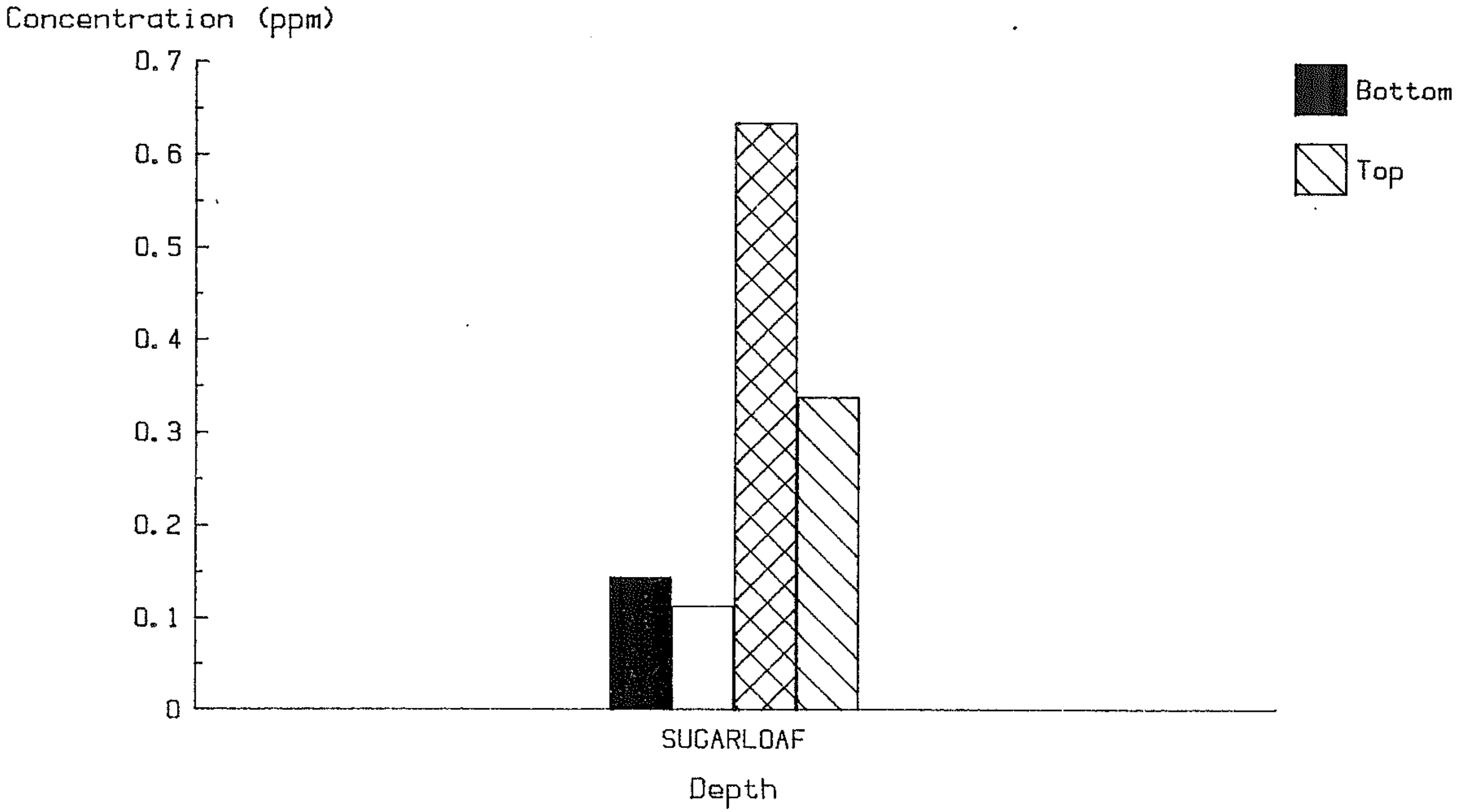
Appendix F-6. Concentrations of Zn in Sediment Core Sections of Santa Fe, Pecos Baldy, and Stewart Lakes



Appendix F-7. Concentrations of V in Sediment Core Sections of Truchas and Sugarloaf Lakes



Appendix F-8. Concentrations of Hg in Sediment Core Sections of Sugarloaf Lake



Appendix G. Summary of Linear Regression Coefficients for Metal Trends in Lake Cores

Appendix G. Summary of Linear Regression Coefficients for Metal Trends in Lake Cores*

Lake	Trace Metals										Major Metals			
	Al	Cr	Cu	Fe	Hg	Mn	Ni	Pb	V	Zn	Ca	K	Mg	Na
Sugarloaf	.25	.49	-.21	-.81	-.90	-.32	-1.0	-.10	-.95	-.52	-.79	-.79	-.52	-.65
Johnson	.10	-.86	.27	-.06	-.39	-.10	-.26	-.71	-.17	-.64	-.27	-.93	-.22	.48
Katherine	-.89	-.75	-.64	.66	-.26	.84	-.72	-.69	-.48	-.32	.13	.91	-.79	.30
Nambe	-.54	-.74	.78	-.52	-.64	.63	-.86	-.86	-.24	-.43	-.52	-.32	-.46	-.08
Pecos Baldy						-.80	.90	-.74		-.79				
Santa Fe	-.16	-.25	-.15	-.70	.39	-.38	.07	-.73	-.46	-.92	-.58	-.39	-.14	.10
Spirit	.03	-.78	-.60	.90	-.48	-.13	-.14	-.25	.85	-.20	-.73	.96	.38	.08
Stewart	.29	.49	-.21	-.08	.66	.51	.09	-.60	.58	-.75	-.03	.08	.31	-.002
Truchas	.02	-.50	-.65	-.89	.13	-.77	-.36	-.92	-.74	-.55	-.26	.27	-.25	.17
Lost	.44	-.25	-.11	-.02	.13	-.41	.63	-.18	.09	.45	-.36	.42	-.67	-.20

* Values were calculated from the bottom to the top of the core; therefore, the negative values are of interest.

Appendix H. Summary of Trace Metal Average Concentrations for the Top and Bottom of the Sediment Cores, CEF Values and EF Values

Appendix H. CEF and EF Ratios of Metal Concentrations for Lake Sediment Cores. Averages were taken for the top two and bottom two sections, except for CLC Pond, Horseshoe, and Sugarloaf Lakes, which were the top sample divided by the bottom sample as a result of the short core depth.

Lake and Metal	Average Top	Average Bottom	CEF	EF
CLC Pond				
Al	12600	47600	.27	.39
Cr	23	41	.56	.83
Cu	40	42	.95	1.41
Fe	14100	20800	.68	1.0
Hg	2.43	1.84	1.32	1.95
Mn	238	370	.64	.95
Ni	16	17	.94	1.39
Pb	100	114	.88	1.29
V	36	42	.86	1.26
Zn	61	77	.79	1.17
Ca	5990	8230	.72	1.07
K	8060	13500	.60	.88
Na	5140	7000	.73	1.08
Mg	1790	5830	.31	.45
Hidden Lake				
Al	34200	54100	.63	.59
Cr	21	21	1.0	.93
Cu	47	34	1.38	1.28
Fe	15200	14100	1.08	1.0
Hg	7.15	.172	41.6	38.6
Mn	405	373	1.09	1.01
Ni	18	21	.86	.80
Pb	57	28	2.04	1.89
V	31	26	1.19	1.11
Zn	56	47	1.19	1.11
Ca	6860	7290	.94	.87
K	8060	13200	.61	.56
Na	9410	7790	.64	1.12
Mg	4440	6890	.64	.60

Appendix H (Continued)

Lake and Metal	Average Top	Average Bottom	CEF	EF
Lagunitas #3				
Al	10500	33500	.31	.34
Cr	20	20	1.0	1.10
Cu	51	63	.82	.89
Fe	25000	27600	.91	1.0
Hg	.14	.14	1.0	1.10
Mn	352	397	.89	.98
Ni	24	27	.89	.98
Pb	38	47	.81	.89
V	45	50	.90	.99
Zn	58	53	1.10	1.21
Ca	5320	6680	.80	.88
K	6280	12100	.52	.57
Na	3100	8760	.35	1.18
Mg	1060	4350	.24	.27
Sugarloaf				
Al	17700	16400	1.08	.72
Cr	47	40	1.18	.78
Cu	71	42	1.69	1.13
Fe	30500	20300	1.50	1.0
Hg	.34	.15	2.34	1.56
Mn	1150	1140	1.01	.67
Ni	32	23	1.39	.93
Pb	69	66	1.05	.70
V	82	41	2.0	1.33
Zn	87	43	2.0	1.35
Ca	8240	5520	1.49	.99
K	18300	10200	1.80	1.19
Na	14500	10000	1.44	.97
Mg	909	596	1.53	1.02
Johnson				
Al	42800	45600	.94	.98
Cr	30	16	1.88	1.95
Cu	60	67	.90	.98
Fe	12400	12900	.96	1.0
Hg	.46	.20	2.28	2.39
Mn	341	353	.97	1.01
Ni	15	14	1.07	1.12
Pb	57	42	1.36	1.41
V	27	28	.96	1.0
Zn	65	57	1.14	1.19
Ca	4600	4610	1.0	1.04
K	9280	7500	1.24	1.29
Na	8660	9800	.88	.92
Mg	2960	2250	1.31	1.37

Appendix H (Continued)

Lake and Metal	Average Top	Average Bottom	CEF	EF
Katherine				
Al	54100	34200	1.58	1.98
Cr	20	15	1.38	1.66
Cu	72	53	1.36	1.70
Fe	17700	22100	.80	1.0
Hg	.28	.22	1.29	1.60
Mn	447	520	.86	1.07
Ni	17	15	1.13	1.42
Pb	86	76	1.14	1.41
V	42	32	1.33	1.64
Zn	71	69	1.03	1.29
Ca	4560	4450	1.03	1.28
K	11200	21600	.52	.65
Na	11300	11700	.96	1.21
Mg	4110	3000	1.40	17.1
Nambe				
Al	45000	28300	1.59	1.47
Cr	20	9	2.22	2.05
Cu	100	125	.80	.74
Fe	11500	10600	1.08	1.0
Hg	.005	.004	1.25	1.15
Mn	307	342	.90	.83
Ni	12	7	1.71	1.58
Pb	134	53	2.55	2.33
V	26	25	1.04	.96
Zn	51	47	1.10	1.0
Ca	6040	4680	1.29	1.19
K	11700	10700	1.09	.92
Na	9840	9790	1.01	.93
Mg	3360	1980	1.70	1.56
Pecos Baldy				
Al	42200	52200	.81	.83
Cr	39	49	.80	.81
Cu	15	13	1.12	1.18
Fe	17100	17500	.98	1.0
Hg	.002	3.99	.006	.006
Mn	285	218	1.31	1.34
Ni	15	23	.67	.67
Pb	59	40	1.49	1.51
V	37	63	.59	.60
Zn	97	79	1.24	1.26
Ca	5409	4730	1.14	1.17
K	9700	10800	.90	.92
Na	8710	7800	1.12	1.14
Mg	3690	5310	.69	.71

Appendix H (Continued)

Lake and Metal	Average Top	Average Bottom	CEF	EF
Santa Fe				
Al	28200	26600	1.06	.85
Cr	26	24	1.08	.87
Cu	110	113	.97	.78
Fe	17500	14100	1.25	1.0
Hg	2.25	.194	11.6	9.34
Mn	517	327	1.58	1.27
Ni	17	17	1.0	.81
Pb	97	71	1.38	1.10
V	31	29	1.07	.86
Zn	138	56	2.46	2.0
Ca	5270	3790	1.39	1.12
K	10540	9050	1.16	.94
Na	8350	9790	.85	.69
Mg	2940	2880	1.02	.82
Spirit				
Al	24100	29500	.81	1.00
Cr	16	6	2.67	3.26
Cu	29	27	1.06	1.31
Fe	9000	11000	.82	1.0
Hg	.065	.29	.23	.27
Mn	334	331	1.01	1.23
Ni	12	12	1.0	1.22
Pb	99	90	1.11	1.34
V	25	37	.68	.83
Zn	49	48	1.02	1.25
Ca	5650	4760	1.19	1.45
K	9030	10800	.83	1.02
Na	10200	10700	.95	1.10
Mg	1020	1870	.54	.67
Stewart				
Al	26100	55100	.47	.43
Cr	15	33	.45	.41
Cu	43	35	1.23	1.10
Fe	21600	19400	1.11	1.0
Hg	.114	.313	.36	.33
Mn	455	755	.60	.54
Ni	15	18	.83	.75
Pb	87	61	1.43	1.28
V	32	24	1.33	1.20
Zn	86	64	1.35	1.21
Ca	5260	5430	.97	.87
K	1200	12200	.92	.09
Na	10800	10700	1.01	.91
Mg	1660	3420	.49	.44

Appendix H (Continued)

Lake and Metal	Average Top	Average Bottom	CEF	EF
Truchas				
Al	28600	44100	.65	.38
Cr	29	22	1.35	.76
Cu	34	21	1.62	.94
Fe	19000	11000	1.73	1.0
Hg	.637	.125	5.12	2.95
Mn	141	104	1.36	.79
Ni	44	19	2.32	1.34
Pb	94	54	1.74	1.01
V	32	23	1.39	.81
Zn	64	85	1.42	.44
Ca	3690	3390	1.09	.63
K	8520	12100	.70	.41
Na	3520	5100	.69	.40
Mg	4650	3670	1.27	.73
Horseshoe				
Al	49400	51900	.95	1.09
Cr	40	32	1.25	1.42
Cu	41	48	.86	.98
Fe	23200	26500	.88	1.0
Hg	.042	1.35	.03	.036
Mn	337	356	.95	1.08
Ni	20	25	.82	.91
Pb	72	80	.91	1.02
V	56	59	.96	1.08
Zn	101	105	.97	1.10
Ca	7500	8500	.88	1.01
K	18700	17100	1.10	1.25
Na	8450	11400	.74	.85
Mg	6040	6400	.95	1.08
Lost				
Al	10500	13900	.75	.74
Cr	50	41	1.23	1.20
Cu	103	94	1.10	1.07
Fe	30400	29800	1.02	1.0
Hg	.246	.247	.99	.98
Mn	497	417	1.19	.17
Ni	22	30	.73	.72
Pb	80	74	1.08	1.06
V	60	59	1.02	1.0
Zn	52	105	.50	.49
Ca	5740	5050	1.14	1.11
K	17800	18800	.95	.93
Na	9870	9110	1.08	1.06
Mg	1690	776	2.18	2.14

Appendix H (Continued)

Lake and Metal	Average Top	Average Bottom	CEF	EF
Middle Fork				
Al	33500	25700	1.30	1.27
Cr	29	25	1.18	1.13
Cu	80	84	.95	.93
Fe	17500	17000	1.03	1.0
Hg	.024	.036	.67	.65
Mn	328	334	.98	.95
Ni	16	16	1.0	.97
Pb	138	112	1.24	1.20
V	43	40	1.08	1.04
Zn	53	58	.91	.89
Ca	6980	6640	1.05	1.02
K	12500	9850	1.27	1.23
Na	10000	8930	1.13	1.09
Mg	3890	2390	1.63	1.58
Williams				
Al	39200	45300	.86	.72
Cr	28	24	1.17	.98
Cu	197	172	1.15	.96
Fe	31300	26200	1.19	1.0
Hg	.058	1.39	.04	.03
Mn	452	409	1.11	.93
Ni	20	26	.77	.64
Pb	213	291	.73	.62
V	65	56	1.16	.97
Zn	528	515	1.03	.86
Ca	7460	7630	.98	.82
K	15000	11800	1.27	1.06
Na	9260	9600	.96	.81
Mg	3230	4660	.69	.58

Appendix I. Summary of Species Composition and pH Preference of Planktonic Diatoms in Selected High Altitude Lakes

Appendix I-1. Species Composition and pH Preferences of Planktonic Diatoms in Hidden Lake, 1987

Species	pH Preference
Achnanthes lanceolata var. *dubia*	Al
Asterionella formosa	AL
Cocconeis placentula var. *lineata*	AL
Cyclotella stelligera	CN
Diatoma hiemale var. *mesodon*	UTD
Fragilaria brevistriata var. *inflata*	AL
F. pinnata var. *pinnata*	AL
Gomphonema angustatum var. *citera*	UTD
Meridion circulare	AL
Navicula laevissima var. *laevissima*	CN
N. peregrina	AL
N. pupula var. *mutata*	UTD
Nitzschia sigmoidea	AL
Opephora martyi var. *martyi*	AL
Stauroneis anceps var. *gracilis*	AC
S. smithii var. *smithii*	CN
S. phoenicenteron var. *phoenicenteron*	CN
Stephanodiscus astraea var. *minutulus*	ALB
Surirella ovata	AL

AC = Acidophilic
AL = Alkaliphilic
ALB = Alkalibiontic
CN = Circumneutral
UTD = Unable to Determine

Appendix I-2. Species Composition and pH Preferences of Planktonic Diatoms in Stewart Lake, 1987

Species	pH Preference
Achnanthes lanceolata var. dubia	AL
Cocconeis placentula var. euglypta	AL
Cymbella heteropleura var. subrostrata	UTD
Diatoma anceps var. anceps	AL
Eunotia sp.	AC
Fragilaria crotonensis	AL
F. leptostauron var. leptostauron	CN
Hannaea arcus	CN
Meridion circularae var. circularae	AL
Neidium iridis var. ampliatum	UTD
Stauroneis phoenicenteron var. phoenicenteron	CN
Synedra longiceps	UTD
S. parasitica	AL

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix I-3. Species Composition and pH Preferences of Planktonic Diatoms in Santa Fe Lake, 1986 and 1987

Species	pH Preference
Asterionella formosa var. *formosa*	AL
Cocconeis pediculus var. *pediculus*	AL
Eunotia sp.	AC
Fragilaria construens var. *venter*	AL
F. inflata	UTD
F. leptostauron var. *dubia*	CN
F. pinnata var. *subrotundra*	UTD
Navicula laevissima var. *laevissima*	CN
N. pseudoscutiformis var. *pseudoscutiformis*	CN
Stauroneis anceps var. *gracilis*	AC
S. phoenicenteron	CN
Synedra amphicephala var. *austriaca*	UTD

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix I-4. Species Composition and pH Preferences of Planktonic Diatoms in Lower Truchas Lake, 1987

Species	pH Preference
Achnanthes lanceolata var. *dubia*	AL
A. saxonica	UTD
Asterionella formosa	AL
Cymbella lunata	CN
Diatoma anceps var. *anceps*	AL
Eunotia tenella	AC
E. vanheurckii var. *intermedia*	AC
Fragilaria pinnata var. *pinnata*	AL
Frustulia rhomboides var. *capitata*	AC
F. rhomboides var. *saxonica*	AC
Navicula pseudoscutiformis	CN
Pinnularia appendiculata	UTD
P. braunii	AC
Stauroneis anceps var. *gracilis*	AC
S. ignorata var. *ignorata*	UTD
Synedra filiformis var. *exilis*	AL
Tabellaria fenestrata	AC
T. flocculosa	AC

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J. Diatom Analysis of Sediment Core Sections from Santa Fe and Truchas Lakes

Appendix J-1. Diatom Analysis for Santa Fe Lake Core, Section 1 cm (Top)

Name	Number Cells Counted	pH Preference
Cyclotella meneghiniana	2	AL
Cymbella lunata var. lunata	1	CN
Fragilaria brevistriata var. brevistriata	3	AL
F. construens var. venter	117	AL
F. pinnata var. pinnata	21	AL
F. vaucheriae var. vaucheriae	1	AL
Melosira distans var. alpigena	4	CN
M. granulata var. granulata	7	AL
M. italica var. italica	7	CN
Navicula laevissima var. laevissima	178	CN
N. minima var. minima	20	AL
N. pupula var. mutata	10	UTD
N. radiosa var. radiosa	4	CN
N. radiosa var. tenella	1	CN
N. subminiscula var. subminiscula	1	UTD
Nitzschia gracilis	3	CN
Opephora martyi var. martyi	1	AL
Pinnularia abaujensis var. abaujensis	5	AC
P. biceps var. biceps	1	AC
P. subcapitata var. subcapitata	76	UTD
Stauroneis anceps f. gracilis	36	AC
S. phoenicenteron var. phoenicenteron	6	CN

Appendix J-1 (Continued)

Name	Number Cells Counted	pH Preference
Synedra amphicephala var. *austriaca*	4	UTD
S. minuscula var. *minuscula*	7	AL
S. parasitica var. *parasitica*	1	UTD
S. rumpens var. *rumpens*	3	CN
S. tenera var. *tenera*	10	AC
Total Cells	530	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-2. Diatom Analysis for Santa Fe Lake Core, Section 5 cm from Top

Name	Number Cells Counted	pH Preference
Achnanthes lanceolata var. *dubia*	8	AL
A. plonensis Hust.	3	UTD
Cyclotella meneghiniana var. *meneghiniana*	1	AL
Cymbella cistula var. *cistula*	1	AL
C. lunata var. *lunata*	2	CN
C. minuta var. *minuta*	2	CN
Fragilaria brevistriata var. *brevistriata*	49	AL
F. construens var. *venter*	70	AL
F. crotonensis var. *crotonensis*	10	AL
F. leptostauron var. *dubia*	53	CN
F. pinnata var. *pinnata*	18	AL
Gomphonema gracile var. *gracile*	1	CN
G. parvulum var. *parvulum*	3	CN
Hantzschia amphioxyses var. *amphioxyses*	1	AL
Melosira ambiqua	20	AL
Melosira distans var. *alpigena*	39	CN
Navicula cryptocephala var. *cryptocephala*	1	AL
N. laevissima var. *laevissima*	66	CN
N. minima var. *minima*	9	AL
N. minuscula var. *minuscula*	3	UTD
N. pupula var. *mutata*	2	UTD
N. radiosa var. *radiosa*	6	CN

Appendix J-2 (Continued)

Name	Number Cells Counted	pH Preference
Nitzschia gracilis var. gracilis	3	CN
N. palea var. palea	3	CN
Pinnularia abaujensis var. abaujensis	8	AC
P. braunii var. braunii	1	AC
P. brebissonii var. brebissonii	4	UTD
P. legumen var. legumen	1	UTD
P. maior var. maior	1	UTD
P. subcapitata var. subcapitata	50	UTD
Stauroneis anceps f. gracilis	28	AC
S. phoenicenteron var. phoenicenteron	4	CN
Synedra minuscula var. minuscula	5	AL
S. rumpens var. rumpens	33	CN
Surirella biseriata var. biseriata	1	UTD
S. linearis var. constricta	1	UTD
Total Cells	511	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-3. Diatom Analysis for Santa Fe Lake Core, Section 9 cm from Top

Name	Number Cells Counted	pH Preference
Achnanthes lanceolata var. dubia	2	AL
Amphora ovalis var. ovalis	2	AL
Cymbella lunata var. lunata	2	CN
Eunotia tenella var. tenella	2	AC
Fragilaria brevistriata var. brevistriata	9	AL
F. construens var. pumula	4	UTD
F. construens var. venter	146	AL
F. crotonensis var. crotonensis	36	AL
F. leptostauron var. dubia	5	CN
F. pinnata var. pinnata	97	AL
Gomphonema angustatum var. angustatum	2	AL
Melosira ambigua	4	AL
M. distans var. alpigena	25	CN
Navicula laevissima var. laevissima	109	CN
N. minima var. minima	9	AL
N. pupula var. capitata	3	CN
N. pupula var. mutata	5	UTD
N. pupula var. pupula	3	CN
N. radiosa var. radiosa	6	UTD
Pinnularia abaujensis var. subundulata	1	AC
P. braunii var. braunii	4	AC
P. maior var. maior	2	UTD

Appendix J-3 (Continued)

Name	Number Cells Counted	pH Preference
P. subcapitata var. subcapitata	12	UTD
Stauroneis anceps f. gracilis	3	AC
S. phoenicenteron var. phoenicenteron	7	CN
Synedra amphicephala var. austriaca	7	UTD
S. delicatissima var. delicatissima	1	UTD
S. rumpens var. rumpens	14	CN
Total Cells	522	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-4. Diatom Analysis for Santa Fe Lake Core, Section 14 cm from Top

Name	Number Cells Counted	pH Preference
Achnanthes clevei var. *clevei*	1	AL
A. lanceolata var. *dubia*	4	AL
A. linearis var. *linearis*	3	CN
A. saxonica var. *saxonica*	1	UTD
Asterionella formosa var. *formosa*	2	AL
Cymbella lunata var. *lunata*	3	CN
C. minuta var. *silesiaca*	4	UTD
Fragilaria brevistriata var. *brevistriata*	6	AL
F. brevistriata var. *inflata*	21	AL
F. construens var. *venter*	108	AL
F. crotonensis var. *crotonensis*	2	AL
F. leptostauron var. *dubia*	9	CN
F. pinnata var. *pinnata*	59	AL
F. vaucheriae var. *vaucheriae*	2	AL
Gomphonema gracile var. *gracile*	3	CN
Melosira ambigua var. *ambigua*	4	CN
M. distans var. *alpigena*	24	CN
Navicula laevissima var. *laevissima*	70	CN
N. minima var. *minima*	1	AL
N. pupula var. *mutata*	6	UTD
N. pupula var. *pupula*	3	CN
N. radiosa var. *radiosa*	3	CN

Appendix J-4 (Continued)

Name	Number Cells Counted	pH Preference
Navicula radiosa var. *tenella*	3	CN
N. seminulum var. *seminulum*	1	CN
Pinnularia abaujensis var. *subundulata*	1	AC
P. mesogongyla var. *mesogongyla*	2	UTD
P. maior var. *transversa*	2	UTD
P. subcapitata var. *subcapitata*	6	UTD
Stauroneis anceps var. *gracilis*	7	AC
S. phoenicenteron var. *phoenicenteron*	10	CN
Synedra rumpens var. *fragilarioides*	4	CN
S. minuscula var. *minuscula*	4	AL
S. rumpens var. *rumpens*	18	CN
Tabillaria flocculosa var. *flocculosa*	1	AC
Total Cells	398	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-5. Diatom Analysis for Santa Fe Lake Core, Section 18 cm (Bottom)

Name	Number Cells Counted	pH Preference
Achnanthes clevei var. *clevei*	1	AL
A. lanceolata var. *lanceolata*	1	AL
A. levanderi var. *levanderi*	1	CN
A. minutissima var. *minutissima*	3	CN
A. saxonica var. *saxonica*	1	UTD
Asterionella formosa var. *formosa*	12	AL
Cyclotella atomus var. *atomus*	1	UTD
Cymbella lunata var. *lunata*	2	CN
C. minuta var. *silesiaca*	5	UTD
Fragilaria brevistrata var. *inflata*	9	AL
F. construens var. *pumula*	2	UTD
F. construens var. *venter*	212	AL
F. crotonensis var. *crotonensis*	7	AL
F. pinnata var. *pinnata*	84	AL
Gomphonema longiceps var. *longiceps*	2	UTD
Melosira ambigua var. *ambigua*	12	CN
M. distans var. *alpigena*	14	CN
Navicula laevissima var. *laevissima*	57	CN
N. lanceolata	3	AL
N. menisculus var. *upsaliensis*	1	UTD
N. minima var. *minima*	6	AL
N. pseudoscutiformis var. *pseudoscutiformis*	1	CN
N. pupula var. *pupula*	3	CN

Appendix J-5 (Continued)

Name	Number Cells Counted	pH Preference
N. radiosa var. *radiosa*	4	CN
Nitzschia acuta var. *acuta*	1	Al
N. palea var. *palea*	1	CN
Pinnularia abaujensis var. *abaujensis*	1	AC
P. subcapitata var. *subcapitata*	10	UTD
Stauroneis anceps var. *americana*	8	UTD
S. phoenicenteron var. *phoenicenteron*	11	CN
Surirella tenera var. *tenera*	1	UTD
Synedra amphicephala var. *austriaca*	1	UTD
S. minuscula var. *minuscula*	10	AL
S. parasitica var. *parasitica*	6	UTD
S. rumpens var. *rumpens*	13	CN
S. tenera var. *tenera*	1	AC
Total Cells	508	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-6. Diatom Analysis for Truchas Lake Core, Section 1 cm (Top)

Name	Number Cells Counted	pH Preference
Achnanthes austriaca	3	AL
A. levanderi var. *levanderi*	6	CN
Cyclotella glomerata	18	AC
C. lunata var. *lunata*	25	CN
Cymbella minuta var. *silesiaca*	11	UTD
Diatoma anceps var. *anceps*	3	AL
Eunotia pectinalis var. *minor*	3	CN
Fragilaria brevistriata var. *brevistriata*	2	AL
F. construens var. *pumila*	8	UTD
F. construens var. *venter*	24	AL
F. pinnata var. *pinnata*	19	AL
Frustulia rhomboides var. *amphipleuroides*	3	CN
Gomphonema parvulum var. *parvulum*	10	CN
Mastogloia smithii var. *smithii*	1	AL
Melosira distans var. *alpigena*	3	CN
M. italica var. *italica*	2	CN
Navicula minima var. *minima*	9	AL
N. pupula var. *pupula*	9	CN
Neidium affine var. *affine*	14	AL
N. bisulcatum var. *bisulcatum*	3	CN
Pinnularia abaujensis var. *abaujensis*	20	AC
P. brebissonii var. *brebissonii*	51	UTD

Appendix J-6 (Continued)

Name	Number Cells Counted	pH Preference
Pinnularia maior var. *maior*	15	UTD
P. subcapitata var. *subcapitata*	194	UTD
Stauroneis anceps var. *gracilis*	39	AC
S. phoenicenteron var. *phoenicenteron*	3	CN
Surirella biseriata var. *constricta*	4	UTD
S. ovata var. *ovata*	3	AL
Synedra amphicephala var. *amphicephala*	12	UTD
Total Cells	517	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix J-7. Diatom Analysis for Truchas Lake Core, Section 21 cm (Bottom).

Name	Number Cells Counted	pH Preference
Achnanthes affinis var. affinis	4	AL
A. lanceolata var. lanceolata	2	AL
A. levanderi var. levanderi	2	CN
A. linearis f. curta	6	UTD
Asterionella formosa var. formosa	4	AL
Cyclotella glomerata	16	AC
Cymbella lunata var. lunata	33	AL
C. minuta var. silesiaca	19	UTD
C. naviculiformis var. naviculiformis	4	CN
Diatoma anceps var. anceps	2	AL
Eunotia pectinalis var. minor	2	CN
E. serca var. diadema	1	AC
Fragilaria construens var. venter	118	AL
F. pinnata var. pinnata	69	AL
F. virescens	11	CN
Hantzschia amphioxys var. amphioxys	3	AL
Melosira distans var. alpigena	10	CN
M. italica var. tenuissima	5	UTD
Navicula minima var. minima	13	AL
N. pupula var. pupula	4	CN
N. radiosa var. tenella	4	CN
Nitzschia palea var. palea	9	CN

Name	Number Cells Counted	pH Preference
Pinnularia abaujensis var. rostrata	6	AC
P. brebissonii var. brebissonii	9	UTD
P. mesolepta var. angusta	4	UTD
P. subcapitata var. subcapitata	106	UTD
Stauroneis anceps f. gracilis	19	AC
Synedra radians var. radians	14	AL
S. rumpens var. fragilarioides	13	CN
Tabellaria flocculosa var. flocculosa	6	AC
Total Cells	518	

AC = Acidophilic
AL = Alkaliphilic
CN = Circumneutral
UTD = Unable to Determine

Appendix K. Summary of Benthic Macroinvertebrate Taxa and Densities

Appendix K-1. Benthic Macroinvertebrate Taxa and Density (number/m^2) Collected in Lakes on the Brazos Uplift of Northcentral New Mexico, 1987*

Taxa	Hidden 4 m 06-20-87	Lagunitas #3 3 m 06-23-87	Sugarloaf 3 m 06-22-87
Diptera - true flies			
Chironomidae (midges)			
Chironomus tentans	546		1820
Tanytarsus sp.	126		
Procladius sp.	630		
Chaoborus sp. (phantom midges)		392	1260
Copepoda - copepods	294		
Collembola - springtails			14
Amphipoda - scuds			
Gammarus sp.	28		
Pelecypoda - clams			
Sphaeriidae (fingernail clams)	994	42	
Nematoda - roundworms		112	
Oligochaeta - worms			
Limnodrilus hoffmeisteri	1050		
Hirudinea - leeches			
Erpobdellidae	14		
Helobdellidae	14		
Total number of organisms/m^2	3696	546	3094
Diversity Index (H)	2.44	1.10	1.01
Total Taxa	9	3	3

* sample collected near or at maximum lake depth (within the trophogenic zone, 2.7 x the Secchi disk depth).

Appendix K-2. Benthic Macroinvertebrate Taxa and Density (number/m^2) Collected in Several High Mountain New Mexico Lakes in the Pecos Wilderness Area, 1986 and 1987*

Taxa	Katherine 6 m 07-07-86	Katherine 20 m 07-07-86	Johnson 7 m 07-08-86	Lower Truchas 3 m 07-10-87
Diptera - true flies				
Chironomidae (midges)				
Chironomus tentans	1523		98	420
Tanytarsus sp.	113			2380
Procladius sp.			196	560
Amphipoda - scuds				
Gammarus sp.	14			
Pelecypoda - clams				
Sphaeriidae (fingernail clams)	2298		154	294
Oligochaeta - worms				
Limnodrilus hoffmeisteri	254	766	266	350
Hirudinea - leeches				
Helobdellidae			14	14
Total number of organisms/m^2	4202	766	728	4018
Diversity Index (H)	1.42	0	2.01	1.80
Total Taxa	5	1	5	6

* sample collected near or at maximum lake depth (within the trophogenic zone, 2.7 x the Secchi disk depth).

Appendix K-3. Benthic Macroinvertebrate Taxa and Density (numbers/m^2) Collected in High Mountain New Mexico Lakes in the Pecos Wilderness Area, 1986*

Taxa	Nambe 1 m 07-26-86	Pecos Baldy 3.5 m 08-17-86	Stewart 10 m 06-02-86	Spirit 4 m 06-04-86
Trichoptera - caddisflies				
Limnephilidae	14			
Ephemeroptera - mayflies				
Callibaetis sp.			28	
Diptera - true flies				
Chrionomidae (midges)				
Chironomus tentans	409		860	71
Tanytarsus sp.	663	804	522	6557
Procladius sp.	1636			437
Ceratopogonidae (biting midges)				14
Copepoda - copepods	395			
Amphipoda - scuds				
Gammarus sp.				1537
Pelecypoda - clams				
Sphaeriidae (fingernail clams)	28	14		
Oligochaeta - worms				
Limnodrilus hoffmeisteri		155	2002	
Hirudinea - leeches				
Erpobdellidae	14			14
Helobdellidae	28			42
Total number of organisms/m^2	3187	973	3412	8672
Diversity Index (H)	1.91	0.74	1.42	1.09
Total Taxa	8	3	4	7

* sample collected near or at maximum lake depth (within the trophogenic zone, 2.7 x the Secchi disk depth).

Appendix K-4. Benthic Macroinvertebrate Taxa and Density (number/m^2) Collected in Santa Fe Lake in the Pecos Wilderness Area, 1986 and 1988*

Taxa	Santa Fe					
	7 m 05-25-86	5 m 07-01-87	6.5 m 08-11-87	6 m 11-12-87	5.5 m 03-17-88	6 m 06-14-88
Trichoptera - caddisflies						
Limnephilidae		182				
Diptera - true flies						
Chironomidae (midges)						
Chironomus tentans	240	28	784	448	6440	
Tanytarsus sp.	4301	84	512	70	7000	3290
Procladius sp.	4822	336	210		560	2100
Cladocera - water fleas				322		
Amphipoda - scuds						
Gammarus sp.		98				
Hydracarina - water mites				28	42	28
Pelecypoda - clams						
Sphaeriidae (fingernail clams)	155	518	112		770	546
Nematoda - roundworms			56			14
Oligochaeta - worms						
Limnodrilus hoffmeisteri		224				14
Hirudinea - leeches						
Erpobdellidae					14	
Helobdellidae		28			28	
Total number of organisms/m^2	9518	1498	1674	868	14,854	5992
Diversity Index (H)	1.25	2.51	1.82	1.48	1.48	1.40
Total Taxa	4	8	5	4	7	6

* sample collected near or at maximum lake depth (within the trophogenic zone, 2.7 x the Secchi disk depth).

Appendix K-5. Benthic Macroinvertebrate Taxa Collected in High Mountain New Mexico Lakes in the Carson National Forest and Wheeler Peak Wilderness Area, 1986*

Taxa	Horseshoe 3 m 07-17-86	Lost 6 m 07-16-86	Middle Fork 4 m 07-15-86	Williams 2 m 07-19-86
Trichoptera - caddisflies				
Limnephilidae		14		42
Diptera - true flies				
Chironomidae (midges)				
Chironomus tentans			733	1534
Tanytarsus sp.	99	113		522
Procladius sp.		2369	353	663
Ostracoda - seed shrimps	437	14		
Amphipoda - scuds				
Gammarus sp.			56	
Pelecypoda - clams				
Sphaeriidae (fingernail clams)	3455	5090	1241	2764
Oligochaeta - worms				
Limnodrilus hoffmeisteri	437	310		56
Total number of organisms/m^2	4428	7910	2383	5581
Diversity Index (H)	1.06	1.23	1.55	1.82
Total Taxa	4	6	4	6

* sample collected near or at maximum lake depth (within the trophogenic zone, 2.7 x the Secchi disk depth).

Appendix L. Summary of Lake Zooplankton Taxa and Densities

Appendix L-1. Zooplankton Taxa and Density in Vertical Tows in Brazos Uplift Lakes in 1987*

Taxa	Hidden 4 m 06-20-87	Lagunitas 3 m 06-23-87	Sugarloaf 3 m 06-21-87
Ceriodaphnia sp.	105		
Daphnia sp.	5,368	50	940
Total Cladocera	5,473	50	940
Cyclopoid Copepoda	53		
Calanoid Copepoda	5,368	112	239
Nauplii	53		
Total Copepoda	5,474	112	239
Chironomidae (pupae)	53		
Ephemeroptera			14
Total Others	53		14
Conochiloides sp.	1,025		
Keratella quadrata			112
Others (Contracted)			1,459
Polyarthra sp.	1,025		
Testudinella sp.	175		
Total Rotifera	17,081	2,495	1,571
Excluding Rotifera			
Total Numbers/m^3	11,000	162	1,193
Total Taxa	5	2	2

* vertical tows from deepest portion of lake to the surface

Appendix L-2. Zooplankton Taxa and Density in Vertical Tows in Pecos Wilderness Lakes During 1986 and 1988*

Taxa	Katherine 20 m 07-07-88	Nambe 1 m 07-26-86	Pecos Baldy 3.5 m 08-17-86
Chydorus sp.	21	158	4,008
Ceriodaphnia sp.	11		
Daphnia sp.	27	11	78,908
Total Cladocera	59	169	82,916
Cyclopoid Copepoda	363	11	752
Calanoid Copepoda	1,689	147	20,040
Harpacticoid Copepoda		34	
Total Copepoda	2,052	192	20,792
Chironomidae (pupae)			251
Chaoborus sp.		11	
Total Other		11	251
Bdelloid Rotifera			167
Conochilus sp.	6,896		501
Keratella sp.			668
Trichocera sp.	6		
Asplanchna sp.	11		835
Total Rotifera	6,913		2,171
Excluding Rotifera			
Total Numbers/m^3	2,111	372	103,959
Total Taxa	5	6	4

* vertical tows from deepest portion of lake to the surface

Appendix L-3. Zooplankton Taxa and Density in Vertical Tows in Pecos Wilderness Lakes During 1986*

Taxa	Santa Fe 05-25-86 6.5 m	Spirit 06-04-86 4 m	Stewart 06-02-86 10 m
Alona sp.	6		
Chydorus sp.		30	9
Ceriodaphnia sp.		450	175
Daphnia sp.	202		26
Total Cladocera	208	480	210
Cyclopoid Copepoda	392	20	430
Calanoid Copepoda	150	100	
Nauplii	2,193	50	35
Total Copepoda	2,735	170	465
Chironomidae (pupae)	17	20	
Ostracoda	35		
Total Other	52	20	
Filinia sp.			
Conochilus sp.		7,659	211
Keratella sp.	28,070	55	6,737
Polyarthia sp.			9,544
Synchaeta sp.			6,877
Total Rotifera	28,070	7,714	23,369
Excluding Rotifera			
Total Numbers/m^3	2,995	670	675
Total Taxa	7	6	5

* vertical tows from deepest portion of lake to the surface

Appendix L-4. Zooplankton Taxa and Density in Vertical Tows in Santa Fe Lake in the Pecos Wilderness in 1987*

Taxa	Santa Fe 6 m 07-01-87	Santa Fe 5.5 m 08-11-87	Santa Fe 5 m 09-03-87	Santa Fe 4.5 11-12-87	Santa Fe 5 m 12-16-87
Bosmina sp.					91
Daphnia sp.	1,737	13,397	24,460	4,912	8,575
Total Cladocera	1,737	13,397	24,460	4,912	8,666
Cyclopoid Copepoda	605	638	1,179		1,825
Calanoid Copepoda	118	17,065	39,785	58,947	4,196
Nauplii	53	160			
Total Copepoda	776	17,863	40,964	58,947	6,021
Chironomidae (pupae)		319	884	263	
Ostracoda	13			88	
Ephemeroptera					7
Hemiptera	13				
Odonata	13				
Total Others	39	319	884	351	7
Conochilus sp.	1,842	2,472	9,432	385,814	
Keratella sp.	53				
Keratella quadrata	105				
Others (Contracted)	3,684	9,107			4,257
Polyarthra sp.			10,611		
Synchaeta sp.		319			
Bdelloida		260	2,358		
Total Rotifera	5,684	12,158	22,401	385,814	4,257
Excluding Rotifera					
Total Numbers/m^3	2,552	31,579	66,308	64,210	14,694
Total Taxa	7	5	4	4	5

* vertical tows at or near deepest portion of lake to the surface

Appendix L-5. Zooplankton Taxa and Density in Vertical Tows in Santa Fe Lake in the Pecos Wilderness in 1988*

Taxa	Santa Fe 5 m 02-11-88	Santa Fe 5 m 03-17-88	Santa Fe 5.5 m 04-09-88	Santa Fe 4 m 05-12-88	Santa Fe 5 m 05-27-88	Santa Fe 6 m 06-14-88
Bosmina sp.	210			67		
Daphnia sp.	27,789	5,553	198	77	176	13,377
Simocephalus sp.					8	
Total Cladocera	27,999	5,553	198	144	184	13,377
Cyclopoid Copepoda		87	140	154		
Calanoid Copepoda	2,526	564	108	19	15	110
Nauplii	210			10		
Total Copepoda	2,736	651	248	183	15	110
Chironomidae (pupae)	210	13	10			
Ostracoda		13				110
Total Others	210	26	10			110
Conochiloides sp.	2,947		110	257	327	
Conochilus sp.						
Brachionus sp.			55			
Keratella quadrata		477	55		264	
Asplanchna sp.						731
Monostyla sp.						292
Others (Contracted)	9,684	26,246	8,235	7,076	6,386	21,053
Polyarthra sp.			387	10,292		
Synchaeta sp.	140		55		82	
Bdelloida	421			129	164	292
Total Rotifera	13,192	26,723	8,897	17,754	7,205	23,246
Excluding Rotifera						
Total Numbers/m^3	30,945	6,204	472	338	199	13,796
Total Taxa	5	3	5	6	3	2

* vertical tows at or near deepest portion of lake to the surface

Appendix L-6. Zooplankton Taxa and Density in Vertical Tows in Wheeler Peak Wilderness Lakes During 1986*

Taxa	Lost 6.5 m 07-18-86	Middle Fork 12 m 07-15-86	William 2 m 07-19-86
Streblocerus sp.			18
Alonella sp.			18
Alona sp.			53
Chydorus sp.	108		
Ceriodaphnia sp.		44	
Daphnia sp.	22,344	6,366	158
Total Cladocera	22,452	6,410	247
Cyclopoid Copepoda	5,127	307	70
Calanoid Copepoda		1,712	
Total Copepoda	5,127	2,019	70
Chironomidae (pupae)		234	
Total Other		234	
Filinia sp.	108		
Conochilus sp.			
Keratella sp.			
Total Rotifera	108		
Excluding Rotifera			
Total Numbers/m^3	27,579	8,663	317
Total Taxa	3	5	5

* vertical tows from deepest portion of lake to the surface

Appendix M. Mineralogies of Lake Sediments and Rock Types

Appendix M. The following are the mineralogies of the lake sediments, as well as a brief description of the rock types found in the drainage basin above each lake. Some minerals are listed "possibly present". It is uncommon for all peaks indicated in the American Society of Testing and Materials files for a mineral to actually occur on a diffractogram. This is caused by lack of perfectly random orientation or very low intensity peaks caused by the mineral being present in only trace amounts. Minerals listed as "possibly present" are minerals for which the diffractograms and the ASTM file did not match up reasonably well or are minerals which matched up fairly well, but their presence is unlikely given the type of rocks found in the basin.

CLC Pond

Location:	Rio Arriba County, NM
Mountain Range:	Tusas Mountains
Quadrangle:	Brazos Peak (7 1/2 min.)

This shallow, swampy basin has been mostly silted in. It contains andesitic volcanic breccia.

Sediment Mineralogy: quartz, plagioclase, muscovite

Clay Fraction:

Clay Mineral	Parts in Ten* CLC-2
smectite	1
kaolinite	3
mixed layer illite/smectite	7

*As a result of errors introduced by rounding off, the sum of all of the clay mineral components do not always add up to ten.

Appendix M (Continued)

Hidden Lake

Location:	Rio Arriba County, NM
Mountain Range:	Tusas Mountains
Quadrangle:	Brazos Peak (7 1/2 min.)

Hidden Lake Basin contains a variety of volcanic and volcanoclastic sediments. These rocks consist of rhyolite and quartz latite tuffs, sandstones, conglomerates, and breccias.

Sediment Mineralogy: muscovite, quartz, plagioclase

Clay Fraction:

Clay Mineral	Parts in Ten	
	HL-2	HL-6
illite	1	2
smectite	4	4
kaolinite	3	4
mixed layer illite/smectite	2	0

Lagunitas #3

Location:	Rio Arriba County, NM
Mountain Range:	Tusas Mountains
Quadrangle:	Toltec Mesa (7 1/2 min.)

This lake basin contains rhyolite, latite, and quartz latite tuffs as well as some volcanoclastic sandstones and conglomerates.

Sediment Mineralogy: volcanic rock fragments, muscovite, quartz, plagioclase and another mineral which is probably a zeolite (heulandite?)

Clay Fraction:

	Parts in Ten		
Clay Mineral	LAG-1	LAG-10	LAG-26
smectite	4	9	8
kaolinite	1	0	0
mixed layer illite/smetite	5	1	2

Sugarloaf Lake

Location:	Rio Arriba County, NM
Mountain Range:	Tusas Mountains
Quadrangle:	Brazos Peak (7 1/2 min.)

This basin contains volcanoclastic rocks of intermediate composition. These rocks are mostly andesite to quartz latite breccias, but a small amount of tuffaceous sandstone is also present.

Sediment Mineralogy: volcanic rock fragments, quartz, muscovite

Clay Fraction:

Clay Mineral	Parts in Ten	
	SGL-2	SGL-8
illite	2	2
smectite	0	1
kaolinite	4	4
mixed layer illite/smectite	3	4

Johnson Lake

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Cowles (7 1/2 min.)

Rock types found in this basin are biotite gneiss, biotite granite, megacrystic granodiorite, biotite-sillimanite-quartz gneiss, metamorphic quartz conglomerate, and pegmatite dikes. Common minerals are microcline and plagioclase feldspar, biotite, quartz, sillimanite, muscovite, and garnet.

Sediment Mineralogy:	quartz, muscovite, plagioclase
Clay Fraction:	Most of the clay fraction from this lake proved to be X-ray amorphous. Trace amounts of illite were detected in samples J-2 and J-5 and a trace amount of kaolinite was detected in sample J-11.

Lake Katherine

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Aspen Basin (7 1/2 min.)

Lake Katherine Basin contains quartz diorite, biotite granite, and numerous pegmatite dikes. Much of the quartz diorite contains distinctive pink microcline megacrysts. Some xenoliths of biotite and amphibole gneiss are also present. Common minerals are plagioclase and microcline feldspars, hornblende, biotite, muscovite, quartz, and epidote.

Sediment Mineralogy: muscovite, quartz, plagioclase, microcline, biotite, and hornblende

Clay Fraction:

Clay Mineral	Parts in Ten K-2	Parts in Ten K-6	Parts in Ten K-16
illite	3	2	4
smectite	2	1	1
chlorite	3	3	0
kaolinite	1	2	4
mixed layer illite/smectite	1	2	2

Appendix M (Continued)

Nambe

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Aspen Basin (7 1/2 min.)

Nambe Lake Basin contains Precambrian biotite, quartz, and plagioclase gneiss.

Sediment Mineralogy: quartz plagioclase, muscovite

Clay Fraction:

	Parts in Ten	
Clay Mineral	N-6,7	N-23,24
illite	4	4
kaolinie	5	4
montmorillonite	trace	1
mixed layer illite/smectite	1	trace

Appendix M (Continued)

Pecos Baldy Lake

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Truchas Peak (7 1/2 min.)

The Pecos-Picuris Fault runs through the Pecos Baldy Lake Basin just to the west of the lake. The part of the basin lying to the west of the fault contains the Precambrian Ortega Quartzite. The Ortega Quartzite is virtually pure quartz with local hematite staining. Paleozoic sedimentary rocks occur on the east side of the fault. These rocks consist of quartz sandstone with siliceous cement, calcareous black shales, and fossiliferous fine-grained limestone. Pyrite cubes up to 1/8 mm across occur within the limestone.

Sediment Mineralogy: quartz, plagioclase

Clay Fraction:

Clay Mineral	Parts in Ten	
	PB-6	PB-17
illite	2	2
kaolinite	7	8
mixed layer illite/smectite	1	1

Santa Fe

Location: Santa Fe County, NM

Mountain Range: Sangre de Cristo Mountains

Quadrangle: Aspen Basin (7 1/2 min.)

This small basin contains granodiorite, quartz diorite, biotite gneiss, and numerous pegmatite dikes. Common minerals are quartz, plagioclase and microcline feldspars, muscovite, hornblende, and biotite.

Sediment Mineralogy: muscovite, quartz, plagioclase, microcline

Clay Fraction: The clay fraction of the sediment from this lake contained mostly X-ray amorphous material with only a trace of kaolinite.

Spirit Lake

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Cowles (7 1/2 min.)

Spirit Lake Basin contains Precambrian granite and megacrystic quartz diorite. The granite is pink and foliated with large flattened polycrystalline quartz grains. It contains quartz, plagioclase, potassium feldspar, and biotite. The quartz diorite is dark gray with large pink microcline megacrysts. It contains quartz, plagioclase, potassium feldspar, and biotite.

Sediment Mineralogy: quartz, plagioclase, potassium feldspar, muscovite (wurtzite possibly present)

Clay Fraction:

Clay Mineral	Parts in Ten S-16	 S-30
illite	3	2
chlorite	4	4
kaolinite	3	3
mixed layer illite/smectite	0	1

Appendix M (Continued)

Stewart Lake (1987)

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Cowles (7 1/2 min.)

Stewart Lake Basin contains megacrystic granodiorite, biotite granite, biotite gneiss, amphibole gneiss, and pegmatite. Common minerals are plagioclase and microcline feldspar, biotite, muscovite, hornblende, and quartz.

Sediment Mineralogy: quartz, muscovite, plagioclase, microcline

Clay Fraction:

	Parts in Ten		
Clay Mineral	ST-2	ST-5	ST-11
illite	3	4	2
kaolinite	4	4	4
smectite	0	0	1
mixed layer illite/smectite	3	2	4

Lower Truchas Lake

Location:	Santa Fe County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Truchas Peak (7 1/2 min.)

Truchas Lake Basin lies entirely within the Precambrian Ortega Quartzite. Although this rock is almost entirely quartz, it also contains a wide variety of accessory minerals. These include muscovite, feldspar, specular hematite, piedmontite, garnet, chlorite, and kyanite.

Sediment Mineralogy: muscovite, quartz, plagioclase

Clay Fraction:

	Parts in Ten		
Clay Mineral	T-2	T-6	T-16
illite	2	2	2
kaolinite	6	6	6
smectite	<1	<1	1
mixed layer illite/smectite	1	1	<1

Horseshoe Lake

Location: Taos County, NM

Mountain Range: Sangre de Cristo Mountains

Quadrangle: Wheeler Peak (7 1/2 min.)

The rock types exposed within the Horseshoe Lake Basin consist of Precambrian amphibole gneiss and granite and paleozoic sedimentary rocks. The paleozoic outcrops are approximately 90% quartz sandstone and quartz pebble conglomerate and approximately 10% limestone. The well indurated sandstone and conglomerate are cemented with silica cement. The limestone contains about 1% sandy quartz grains, a few silicified micro-fossils, and a trace of hematite. The Precambrian rocks contain quartz, plagioclase, potassium feldspar, muscovite, and hornblende.

Sediment Mineralogy: quartz, plagioclase, pyrite, muscovite, and possibly sphalerite

Clay Fraction:

	Parts in Ten	
Clay Mineral	H-8,9	H-28,29
illite	5	3
chlorite	3	4
kaolinite	1	1
mixed layer illite/smectite	trace	1

Appendix M (Continued)

Lost Lake

Location:	Taos County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Wheeler Peak (7 1/2 min.)

Lost Lake Basin contains mostly Precambrian tonalite, granite, and amphibole gneiss. These rocks contain quartz, plagioclase and postassium feldspar, muscovite, and hornblende. Some paleozoic sedimentary outcrops occur in this basin as well, and consist of about 95% quartz sandstone and conglomerate and about 5% limestone.

Sediment Mineralogy: muscovite, quartz, plagioclase

Clay Fraction:

Clay Mineral	Parts in Ten		
	L-2	L-5	L-13
illite	4	4	4
chlorite	3	2	3
kaolinite	1	1	1
mixed layer illite/smectite	2	2	2

Appendix M (Continued)

Middle Fork Lake

Location:	Taos County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Wheeler Peak (7 1/2 min.)

Middle Fork Lake Basin contains mostly granite with minor amounts of tonalite, amphibole gneiss, sandstone, shales, and limestone. These rocks contain hornblende, quartz, calcite, plagioclase, and potassium feldspar.

Sediment Mineralogy:	quartz, plagioclase, muscovite, possibly potassium feldspar, sphalerite, hydrobiotite

Clay Fraction:

	Parts in Ten	
Clay Mineral	MF-10,11	MF-31,32
illite	3	3
chlorite	3	3
kaolinite	2	3
mixed layer illite/smectite	2	1

Appendix M (Continued)

Williams Lake

Location:	Taos County, NM
Mountain Range:	Sangre de Cristo Mountains
Quadrangle:	Wheeler Peak (7 1/2 min.)

Williams Lake Basin contains Precambrian amphibolite, amphibole gneiss, granite, and tonalite. These rocks contain hornblende, quartz, plagioclase, and potassium feldspar. Within the amphibole gneiss on the western lakeshore is a massive sulfide vein. Disseminated pyrite occurs within a chloritic zone on either side of the sulfide vein. X-ray diffraction analysis of a sample taken from the vein revealed it to be virtually all pyrite, possibly with some sphalerite.

Sediment Mineralogy: quartz, plagioclase, pyrite, possibly flourite

Clay Fraction:

	Parts in Ten	
Clay Mineral	W-8,9	W-26,27
illite	3	3
chlorite	3	3
kaolinite	2	3
mixed layer illite/smectite	2	1