UMPQUA LAKES BASE-LINE WATER QUALITY INVENTORY

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Report #90-12

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November 14, 1990

A Report to the
Umpqua National Forest
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Executive Summary

Nine lakes in the Umpqua National Forest were sampled in September, 1990. Water quality samples were analyzed for major ion chemistry and related water quality parameters. Special care was exercised in the collection and analysis of the samples to ensure that the data were of the high quality required for dilute surface waters. Two lakes, Calumet and Lucille, have alkalinity values between 5-10 μeq/L, base cation concentrations less than 15 μeq/L, and conductivity values near 3 μS/cm. Both lakes are located in the High Cascades in highly porous pumice soils and lack surface water inlets or outlets. These precipitation-dominated lakes are extremely sensitive to potential degradation from atmospheric contaminants and are strong candidates for periodic monitoring.

One lake, Little Twin, was acidic with a pH of 5.0 and sulfate concentration of nearly 300 μeq/L. The source of the sulfate is from deposits in the watershed, most likely as sulfur crystals or sulfide ores. It is unclear if this is an entirely natural condition or whether past human activities in the watershed have exposed the high-sulfur materials to increased weathering. The mineral acidity (sulfuric acid) in Little Twin Lake makes it an unsuitable habitat for trout. The adjacent lake, Big Twin, also has high sulfate concentrations, but the supply of base cations and bicarbonate from the watershed currently results in a slightly positive alkalinity.

Cliff, Buckeye, and to a lesser extent Fish Lake, are highly productive systems that are insensitive to minor changes in watershed or airshed inputs. However, Cliff Lake is so productive and shallow that prolonged ice cover could result in severe oxygen depletion and subsequent fish kill. The remaining two lakes, Maidu and Skookum, have intermediate concentrations of major ions and are also relatively insensitive to minor changes in atmospheric deposition or watershed activities.

These nine lakes encompass virtually the entire range of chemical attributes of lakes sampled in the Pacific Northwest as part of EPA's Western Lake Survey. The lack of homogeneity in lake chemistry, particularly evident among adjacent lakes, highlights the importance of local watershed controls on lake chemistry. The key factor separating the dilute from the higher base cation lakes appears to be the amount of hydrologic input from the watershed, as reflected in the presence of surface inlets and outlets.

Acknowledgements

We thank Jim DeLapp, Michael Jones, and Barbara Benninghoff at the Umpqua National Forest for sheparding this project and gratefully acknowledge Louise O'Deen with the Rocky Mountain Forest Range Experiment Station for analysis of the lake samples. This work was funded by the Umpqua National Forest under purchase order #43-04T1-0-2123 to E&S Environmental Chemistry, Inc.

Table of Contents

I. INTRODUCTION

Numerous studies in Europe and North America have demonstrated the sensitivity of some aquatic resources to damage from long-range transport of atmospheric deposition. The most widely studied problem associated with atmospheric contaminants is acidification caused by deposition of sulfur and nitrogen. Most lakes and streams acidified by atmospheric deposition are characterized as having low concentrations of base cations (calcium, magnesium, sodium, and potassium). Aquatic systems with ≤ 50 μeq/L of either base cations or alkalinity are considered very sensitive to acidic deposition (Baker et al. 1990). One of the major efforts to collect synoptic data on surface water chemistry in the United States was initiated by the U. S. Environmental Protection Agency. As part of the National Surface Water Survey, lakes in selected areas of the eastern and western United States were sampled from a probability frame (Linthurst et al. 1986; Landers et al. 1987). The Western Lake Survey (WLS) was conducted in a manner similar to the Eastern Lake Survey, but the former was based on a statistical lake frame of 1:100,000- scale maps, whereas the latter was based on 1:250,000-scale maps. The intent of these probability surveys was to provide quantitative estimates of low alkalinity lakes throughout the regions of interest. Therefore, the sampling intensity (720 out of nearly 10,400 lakes) was insufficient to characterize lake populations in many individual national forests or wilderness areas (Eilers et al. 1989). Because of the regional probability design of the WLS, lakes in some areas, such as the Umpqua National Forest, were not sampled.

The purpose of this study was to sample selected lakes in the Umpqua National Forest to provide baseline information for assessing possible future changes, particularly from atmospheric sources. This study attempted to use methods comparable to the WLS because these results serve as a common framework for assessing atmospheric impacts in the region.

The nine lakes selected for sampling are located in the Rogue-Umpqua Divide Wilderness, the Oregon Cascades Recreation Area, and roadless areas within the Umpqua National Forest, Oregon (Figure 1). The Umpqua National Forest is located on the western slope of the Southern

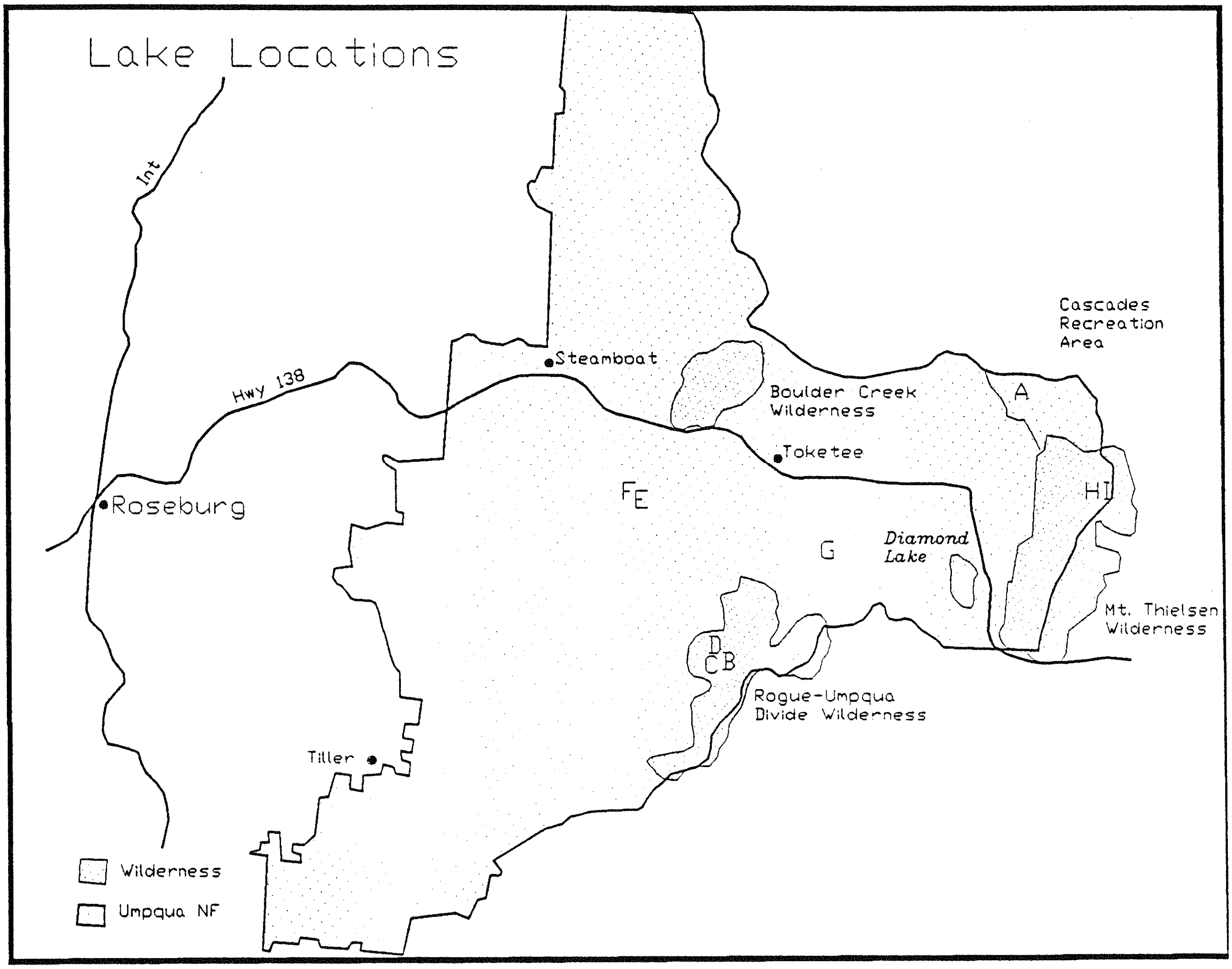

Figure 1. Study area of the Umpqua National Forest. Sample lakes are indicated as letters (A: Calumet; B: Cliff; C: Buckeye; D: Fish; E: Big Twin; F: Little Twin; G: Skookum; H: Lucille; I: Maidu).

Oregon Cascades. All study lakes are located in eastern Douglas County and receive about 60 to 70 inches of annual precipitation. The study area contains portions of two geomorphic regions: the High Cascades to the east and the Western Cascades to the west (Johnson et al. 1985). The High Cascades is largely comprised of recent extrusive igneous rocks such as andesite and basalt, whereas the much older Western Cascades province is more highly weathered andesite and rhyolite (Alt and Hyndman 1978).

II. METHODS

The lakes chosen for sampling were selected by Forest Service staff based on perceived areas of greatest interest for management needs. Consequently, inferences regarding the chemical characteristics of other lakes in the Umpqua National Forest are restricted to those lakes with properties similar to the lakes sampled. The lakes were visited from September 17 to 20, 1990 and photographs were taken at all sites (Appendix A). All lakes were accessed by foot trails and sampled from an inflatable raft positioned near the deepest portion of the lake. Water samples were collected at a depth of 1.5 m using an acrylic 4.2L Van Dorn sampler (Wildco 1940-C65). The water samples were drained into 500 ml amber Nalgene bottles that had been pre-soaked for one week in deionized ultrafiltered water (Fisher W2-20). Two blank samples containing the deionized water used for pre-soaking the samples were submitted to the laboratory as unidentified quality assurance checks; two replicate lake water samples were also submitted as checks on analytical and field precision.

Measurements conducted on site included Secchi disk (25 cm disk) and temperature/conductivity profiles using a YSI meter (Model 3000 TLC). Samples were kept cool in the field in insulated containers with gel-packs until placed in coolers, usually later the same day. Samples were shipped in insulated containers with gel-packs to the laboratory via 48-hour courier service. Samples collected on September 20, 1990 were stored in a refrigerator over the weekend before shipment to the laboratory on the following Monday. All samples arrived at the laboratory still chilled. Analysis of the samples was conducted by the USDA Forest Service at the Rocky Mountain Forest Range Experiment Station, Fort Collins, Colorado.

Prior to analysis, samples were filtered through a 0.45μ membrane filter. Alkalinity and pH were determined with the Radiometer Acid Rain Analysis System using a pH endpoint of 3.5 for the alkalinity titration. Chloride, nitrate, phosphate, and sulfate were analyzed on a Dionex ion chromatograph using peak height measurements; ammonium was determined on the Lachat flow injection analysis (FIA) system. Sodium and potassium were measured using a Thermo Jarrell Ash Atomic Absorption Spectrophotometer, and the remainder of the metals were measured on a Thermo Jarrell Ash ICP system. The standards used for ICP were as follows: Cu, Zn, Pb, V, As, Se, B, Ba, Ni No, Cd, Si, Cr, Sr -1 ppm; Ti, Mn, Fe, Al, Ca, Mg - 10 ppm; Na, K - 20 ppm. Using these standards and samples, the following elements were below the detection limit values: Ni, Mo, Pb, As, Se, B, Ti, Cu, Zn, Cd, Cr, Se, V, Fe, Al. All samples were analyzed in duplicate on the ICP and the results were averaged.

Standard reference materials used for trace metal analyses were SLRS-1, or riverine water reference material from the Marine Analytical Chemistry Standards Program in Canada and U.S. Geological Survey round-robin samples for which the "most probable value" (MPV) is reported. Deionized water from the Forest Service laboratory was used as a blank (0 ppm) in each analysis. Simulated rainwater from the National Institute of Standards and Technology was used to check standards on the ion chromatograph and EPA reference standards were used for checking the Lachat FIA system. "AN" refers to a standard analyzed by the laboratory, as compared to MPV (USGS) or "CERT" which means certified by EPA or by the Canada MACSP.

Barium and strontium were detected in the samples but at parts per billion levels, therefore results from the ICP analyses (other than Ca, Mg, and SiO_2) are not reported.[1] Total phosphorus

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[1] Organic carbon could not be determined at this time due to a malfunctioning carbon analyzer; however, organic carbon concentrations for most of the lakes are expected to be low based on lack of an appreciable anion deficit (e.g., $C_B \approx C_A$), the high transparency of the lake waters (Secchi disk values generally > 5 m), and low color (Table 5).

was also determined on the Lachat system, but these values were considered unreliable and are not used in this report.

The raw data were transferred from the laboratory to E&S on floppy disk (Appendix B) and were entered into SAS (SAS 1988) files for interpretation. The data were reviewed for conformance with quality assurance expectations and were edited prior to final interpretation.

III. RESULTS

A. Field

Physical characteristics of the study lakes and watersheds were determined from 1:24,000 scale topographic maps, previously published information (e.g. Rinella 1979), and site measurements at the lakes (Table 1). The lakes and their respective watersheds are shown on a common scale in Figure 2. The watershed delineations are in general agreement with those presented by Rinella (1979) with the exception of Buckeye Lake. The lake outlet is not at the western end of the lake as originally shown by Rinella (1979), but instead is located at the north side of the lake. In addition, the more recent 1:24,000-scale topographic maps show that the outlet from Buckeye Lake does not flow into Fish Lake as previously shown in the older 1:62,500-scale quadrangle maps.

Field results for the sampled lakes show that most of the lakes were well-mixed at the time of sampling (Figure 3). Only Fish Lake, which is about 40 m deep (~125 ft), and Buckeye Lake demonstrated any appreciable thermal stratification. The shallow depth of most of these lakes minimizes the possibility of any prolonged summertime stratification. Similarly, chemical stratification (as reflected in the conductivity measurements) was generally absent in these lakes in September. Note that the surface field conductivity (temperature compensated) values agreed reasonably well with the more accurate laboratory conductivity measurements (r^2=98.9%).

The lakes were generally very transparent as indicated by the Secchi disk measurements. The Secchi disk was visible on or near the bottom in six of the nine lakes. In the three lakes for

Table 1. Physical characteristics of the sampled lakes and their watersheds in the Umpqua National Forest.

	Latitude[a] (DMS)	Longitude[a] (DMS)	Elevation[a] m (ft)	Lake Area[b] ha (acres)	Watershed Area[b] ha (acres)	Maximum Depth[a] m (ft)	Hydraulic Residence Time[c](yr)	Hydrologic[d] Type	Geology
Calumet	43 21 50	122 06 24	1790 (5870)	6.5 (16)	105.3 (260)	7.0 (23)	0.16	Seepage	Qoba, Qpf(2)[e]
Big Twin (East)[g]	43 13 50	122 35 31	1533 (5029)	5.8 (14)	73.4 (181)	15.2 (50)	0.31	Drainage	Tms[f]
Little Twin (West)[g]	43 13 43	122 35 37	1540 (5040)	2.5 (6)	33.9 (84)	9.1 (30)	0.05	Drainage	Tms[f]
Skookum	43 10 05	122 20 00	1690 (5560)	4.6 (11)	23.0 (57)	6.1 (20)	0.12	Seepage	QTba, Twb[e]
Lucille	43 15 14	122 00 53	1810 (5950)	3.3 (8)	40.5 (100)	4.9 (16)	0.16	Seepage	Qpf(5)[e]
Maidu	43 15 25	121 59 59	1820 (5980)	7.8 (19)	361.2 (892)	3.7 (12)	0.04	Drainage	Qpf(5), Qoba[e]
Cliff	43 12 15	122 42 39	1310 (4300)	3.0 (7)	61.8 (153)	4.3 (14)[h]	0.07	Drainage	Tms, Top[f]
Buckeye	43 03 52	122 31 16	1280 (4200)	4.1 (10)	87.6 (216)	14.3 (47)	0.22	Drainage	Top, Tms[f]
Fish	43 04 46	122 30 23	1038 (3405)	37.9 (94)	1747.0 (4317)	38.1 (125)	0.33	Drainage	Top, Tms[f]

[a] Source: Rinella (1979)

[b] Source: this study, electronically planimetered on 1:24,000 scale USGS topographic maps

[c] Calculated residence time (inflow-based) as shown in Landers et al. (1987) where precipitation was assumed to be 1.8 m/yr and runoff was 1.3 m/yr. Runoff is based on topographic watershed area and residence times for most of these lakes, particularly the seepage lakes, are likely to be much greater.

[d] Seepage - no permanent surface inlets or outlets; Drainage - permanent surface inlets or outlets

[e&f] Source: Sherrod (In Press); Ramp (1972;) Qoba = older basaltic andesite; Qpf = pumice deposits (# is depth in meters); Twb = porphytitic basalt and basaltic andesite; QTba = olivine basalt and olivine-bearing andesite; Tms = Sardine formation, upper layers of andesite flows and lower series of basalt and dacite-andesite flows; Top = massive beds of andesite and dacitic tuff of ash-flow origin.

[g] The Twin Lakes are also known as East and West Twin Lakes, but the names Big and Little are used throughout this report

[h] Source: this study, based on brief examination of the lake (no bathymetric map available)

<u>USGS 1:24000 Topographic Maps</u>
Thielsen Wilderness Watersheds
  Miller Lake, 1967
  Burn Butte, 1967
  Mt. Thielsen, provisional 1985
  Tolo Mountain, provisional 1986
Rogue-Umpqua Divide Area Watersheds
  Fish Mountain, provisional 1989
  Buckeye Lake, provisional 1989
Calumet Lake Watershed
  Cowhorn Mtn, provisional 1986
  Tolo Mountain, provisional 1986
Twin Lakes Watersheds
  Twin Lakes Mtn., provisional 1989
Skookum Lake Watershed
  Garwood Butte, provisional 1985

<u>USGS 1:62500 Topographic Maps</u>
Thielsen Wilderness Watersheds
  Summit Lake, 1956
  Diamond Lake, 1956
Rogue-Umpqua Divide Area Watersheds
  Quartz Mtn., 1955
  Garwood Butte, 1956
Calumet Lake Watershed
  Summit Lake, 1956
Twin Lakes Watersheds
  Quartz Mtn., 1955
Skookum Lake Watershed
  Garwood Butte, 1956

Figure 2. Watershed delineations for the study lakes shown at consistent scales of 1:62,500. Delineations were based on 1:24,000 USGS topographic maps except for Calumet Lake for which only the 1:62,500 scale map was available.

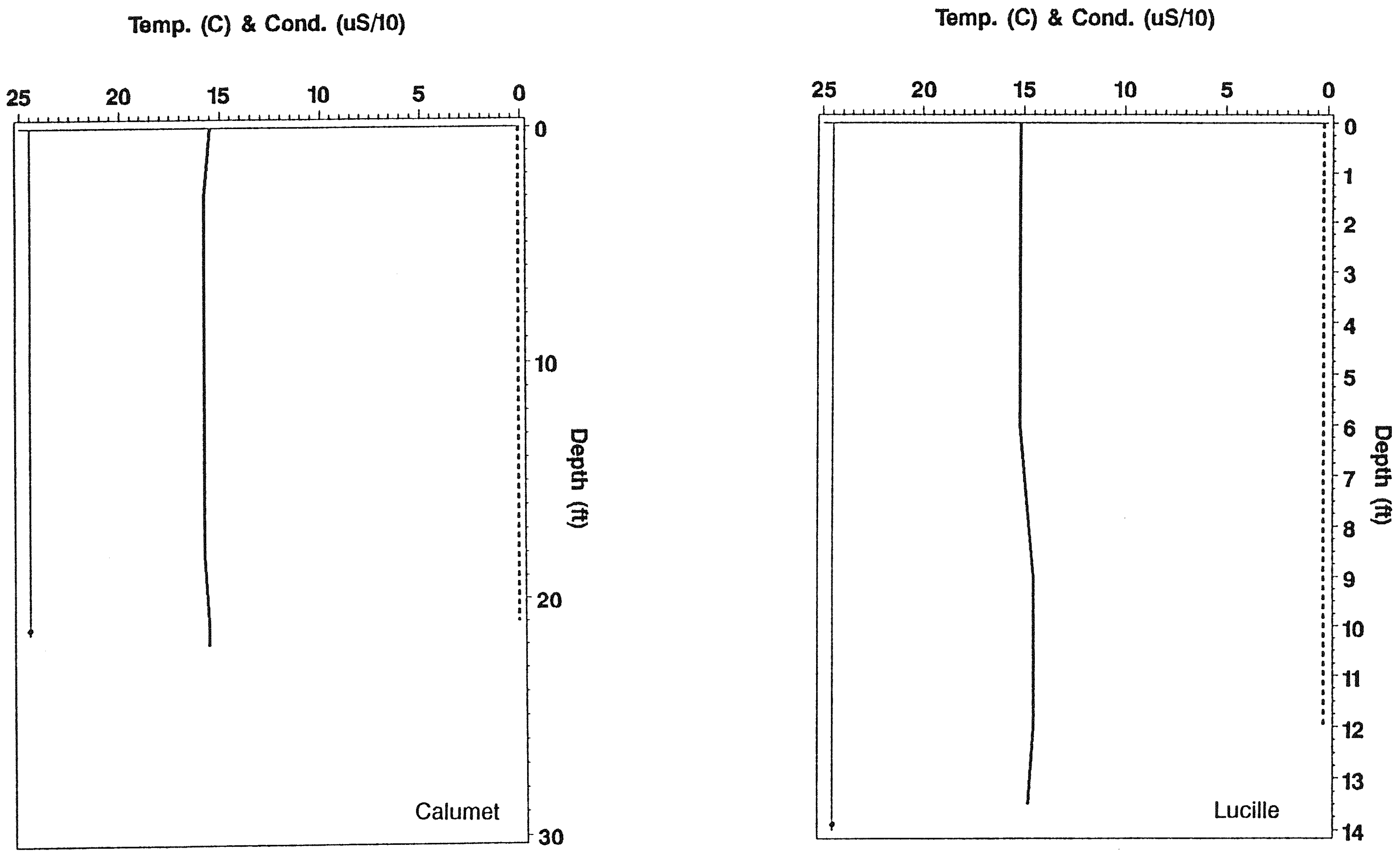
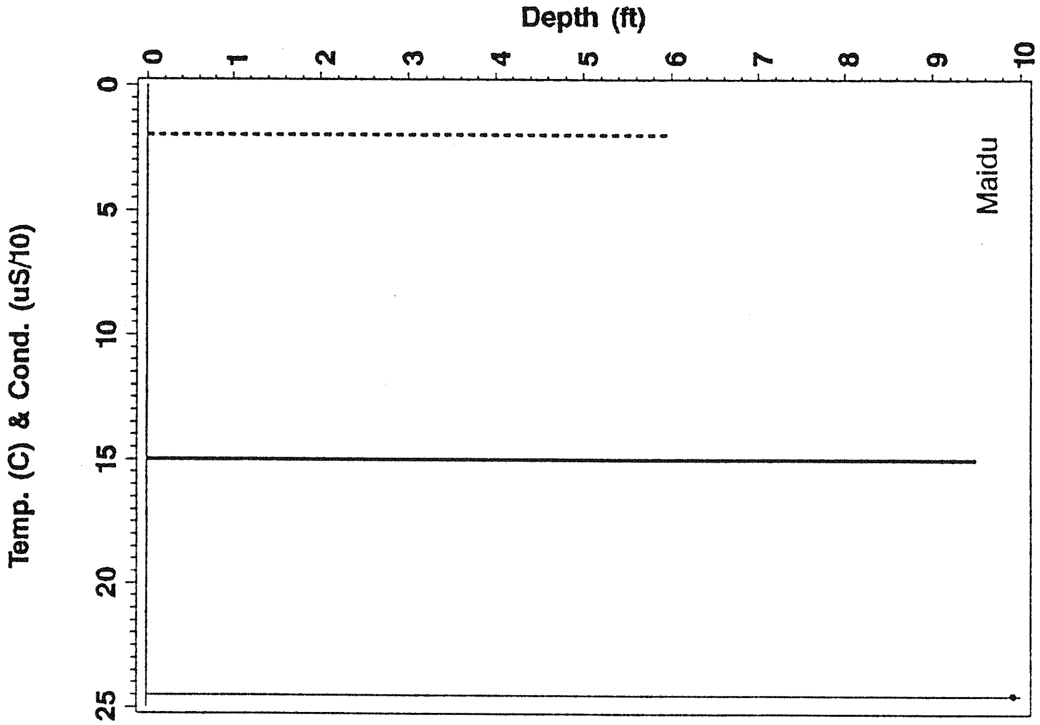


Figure 3. Secchi disk (⭣), temperature (|), and conductivity (¦) profiles for the study lakes in the Umpqua National Forest.



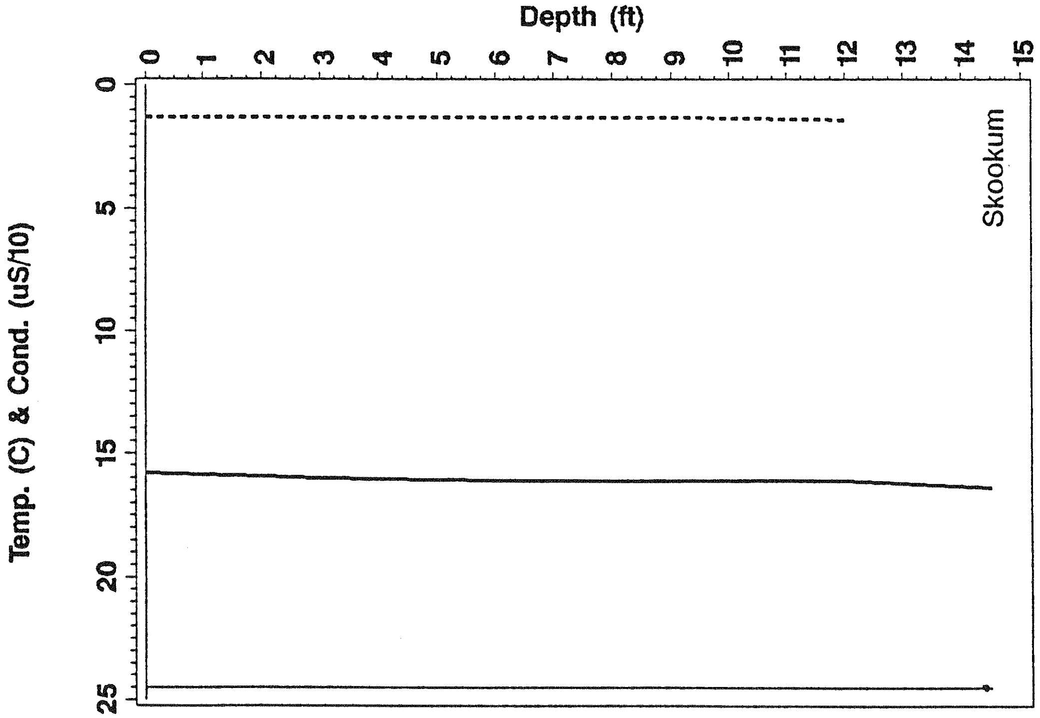
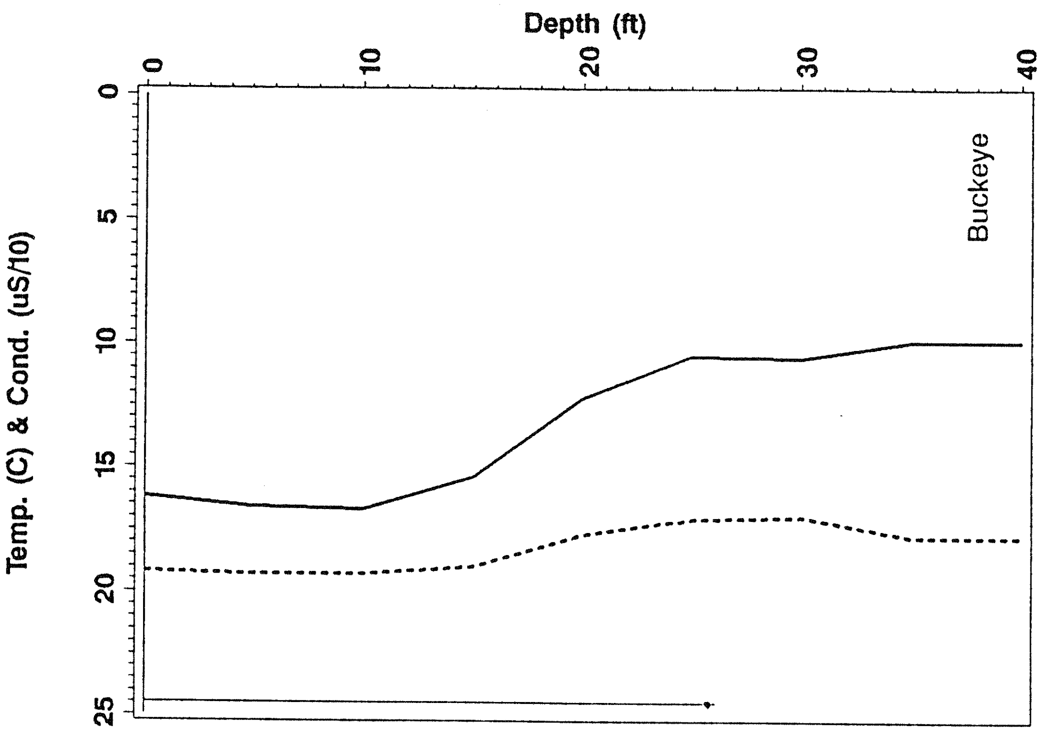


Figure 3. Continued



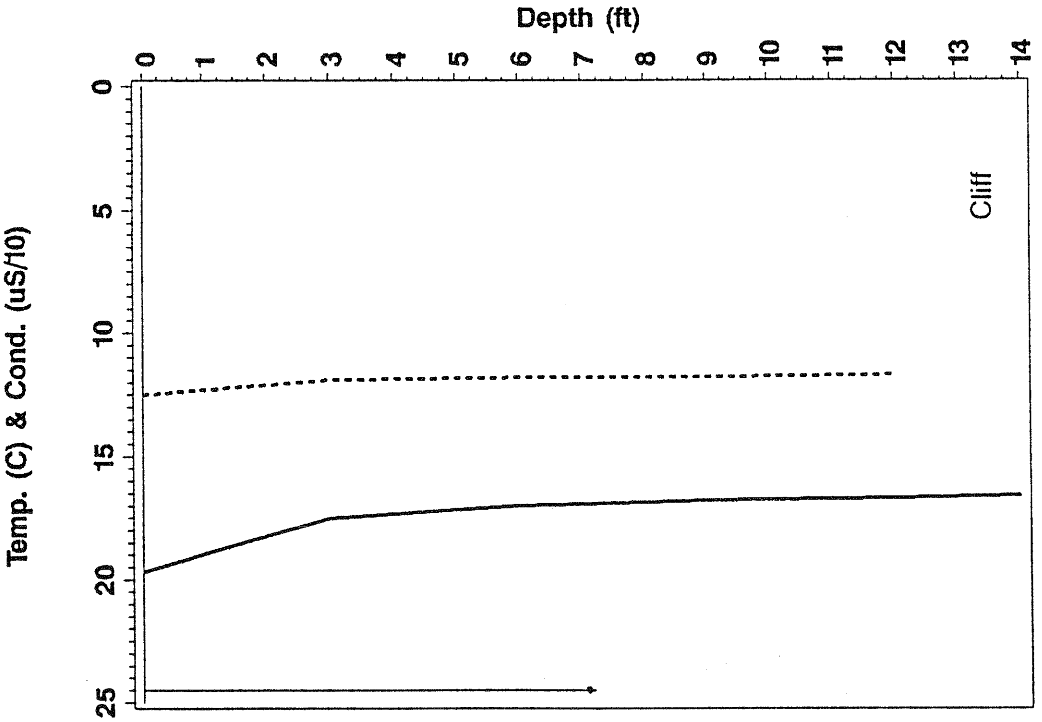
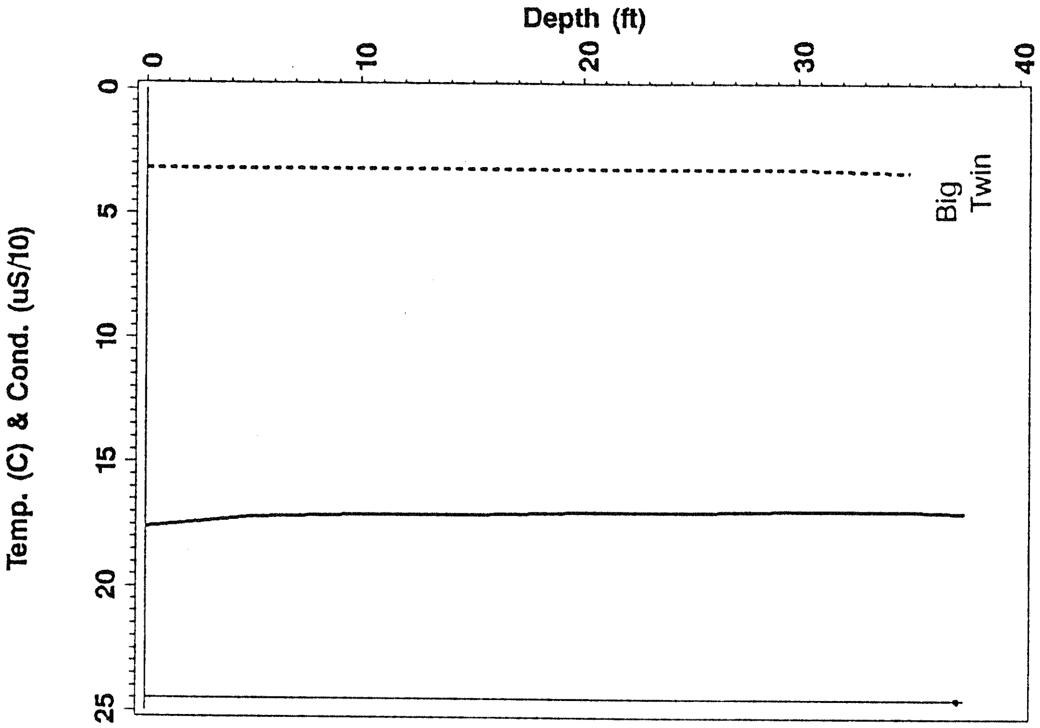


Figure 3. Continued



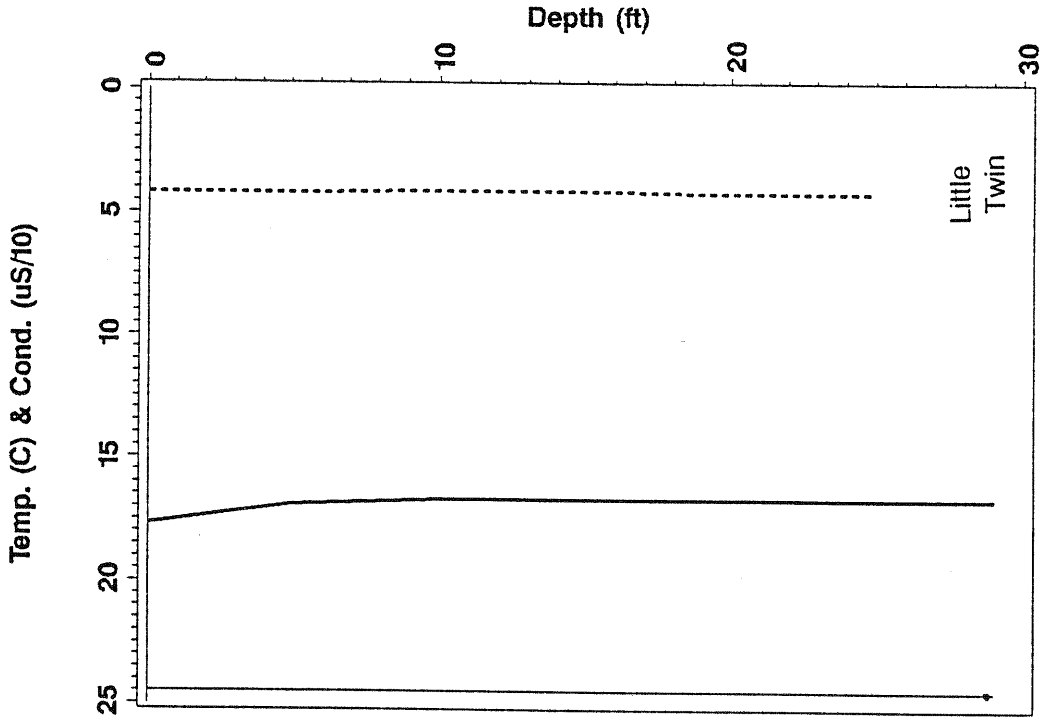


Figure 3. Continued

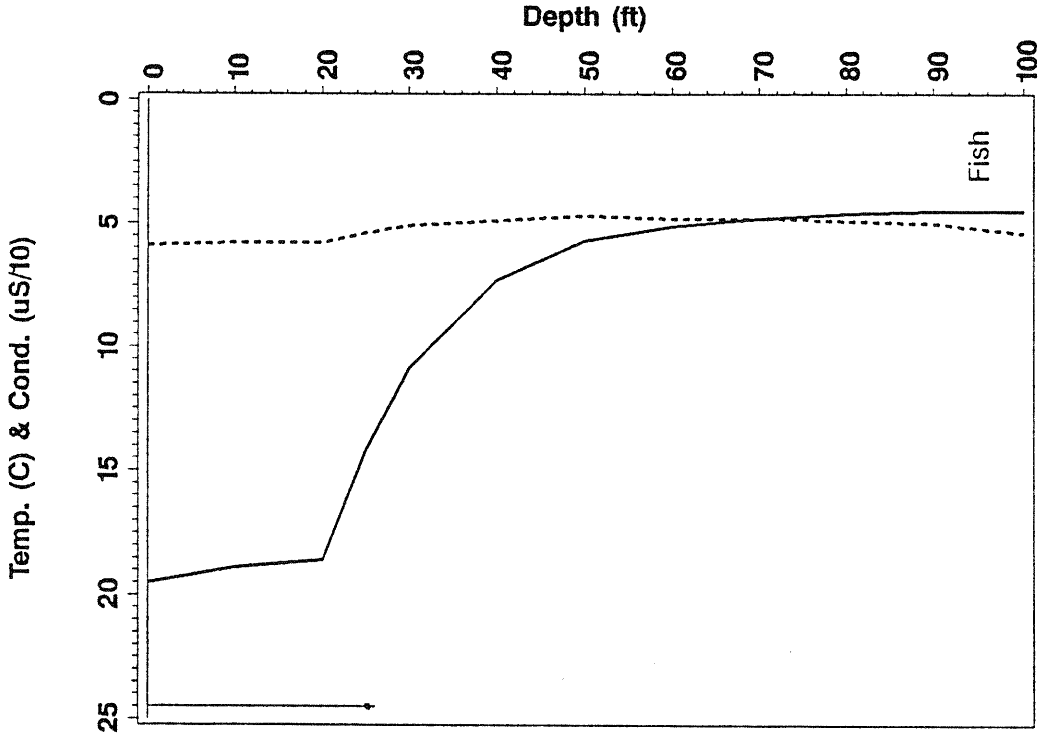


Figure 3. Continued

which a complete measure of transparency was possible, Secchi disk transparency was over 8 m (~ 25 ft) in two lakes; the minimum Secchi disk value (2.1 m; 7 ft) was observed in Cliff Lake, which exhibited extensive macrophyte growth and high turbidity associated with considerable phytoplankton productivity. The high transparency of most of these lakes is indicative of low primary productivity and reflects the low nutrient concentrations measured.

B. Laboratory

Results received from the Rocky Mountain Forest Range Experiment Station were reviewed to identify possible analytical errors. Three types of quality assurance/quality control samples were analyzed: blanks, duplicates, and reference (audit) samples. Results from the three blank samples indicate that contamination (field or laboratory) was not a problem and that the analytical results are not biased at low concentrations (Table 2). pH values were generally within 0.2 units of the expected value and nearly all analytes went undetected in the blank samples. A small positive bias (or contamination) is shown for calcium (OR6); however, the magnitude is insignificant for all but the most dilute lake. Considering that the bias is only evident for calcium suggests that the deionized water used for the field work may be the probable source of the calcium. Therefore, this would not have an impact on the lake sample results.

Analytical and field precision, as shown by the two duplicate samples, is generally very good. Most analyses differed by less than 3% from the paired result (Table 2). However, nitrate and sulfate values for sample OR7 were over 3 μeq/L greater than values for sample OR8. The highest phosphate concentration was also measured from this very dilute lake. These differences are small, yet consistently greater than expected based on the sum of anions and the disparity in calculated versus measured alkalinity. Because of these differences in anions for OR7 and OR8 (Lake Lucille), only the values from sample OR8 are used in the data presentations that follow. No significant differences were noted between samples OR10 and OR11 (Cliff Lake); therefore, the data presentations for this lake are based on the average of these two duplicate samples.

Table 2. Quality assurance results for blank (deionized water) and duplicate lake samples. Units for paramters are μeq/L except for pH (s.u.), conductivity (μS/cm), and SiO_2 (mg/L)

	Blanks			Duplicates			
		Field		Lake Lucille		Cliff Lake	
Parameter	Lab	OR2	OR6	OR7	OR8	OR10	OR11
pH	5.48	5.41	5.53	5.94	5.91	8.24	8.10
ANC	-0.3	-1.3	0.3	7.20	7.30	1461.3	1455.5
Ca^{2+}	0	0.35	2.25	3.04	2.89	533.9	548.9
Mg^{2+}	0	0	0	1.73	1.73	525.0	533.2
Na^+	-	0	0.91	7.13	7.22	252.7	250.1
K^+	-	0	0	1.71	1.79	40.4	40.2
NH_{4+}	0	0.	0.	0.	0.	0.	1.7
Σ Cations	0	0.35	3.16	13.62	13.53	1352.1	1374.1
Cl^-	0	0	0	4.71	4.23	4.53	4.23
NO^-	0	0	0	3.05	0	0	0
SO_4^{2-}	0	0	0	8.58	4.89	54.3	59.8
PO_4^-	0	0	0	0.21	0	0	0
HCO_3	-0.3	-1.3	0.3	7.20	7.30	1461.3	1455.5
Σ Anions	0	0	0.3	23.54	16.42	1520.2	1519.5
M.[b] Conductivity	0.67	1.33	1.46	3.12	3.13	130.6	132.2
T/C[c] Conductivity	1.2	1.4	1.2	2.22	1.70	135.4	136.7
M. Alkalinity	-0.3	-1.3	0.3	7.20	7.30	1461.3	1455.5
T/C Alkalinity	0	0	0	-2.72	4.51	1293.2	1308.4
M. pH	5.48	5.41	5.53	5.94	5.91	8.24	8.10
T/C pH	5.65	5.65	5.65	-	-	-	-
Silica (SiO_2)	0.01	0.05	0.03	0.50	0.53	16.2	16.5

[a] Bicarbonate measured as aklalinity
[b] M = measured
[c] T/C = theoretical or calculated

Several reference samples were analyzed concurrently with the lakes samples and are presented in Table 3. Nearly all analyzed values (AN) are within a few percent of the certified (CERT) or most probable value (MPV). The only cases where lack of agreement is evident is for the calcium results from the Canadian audit sample and for chloride in USGS sample M114. The calcium bias for this one sample is 14.3%; no bias is evident in the other three calcium reference samples. Similarly, the chloride results for M114 are 6.4% greater than the audit value. In neither case is there sufficient evidence to suggest that analytical bias is a serious problem, particularly for the dilute lakes.

Checks of internal consistency of the data were performed by comparing sums of anions versus sums of cations, measured versus calculated conductivity, measured versus calculated alkalinity, and pH versus alkalinity. Plots of sums of anions and cations show generally close agreement for the samples (Figure 4), although there is a consistent overestimation of anions relative to the cations ranging from about 4 to 9%. A check on the measured versus calculated alkalinity (sum of bases [C_B] - sum of acids [C_A]) shows that the measured alkalinity generally exceeds the calculated alkalinity by 10 to 20%. These two results suggest that the measured alkalinity values exhibit a positive bias. When the calculated alkalinity values are substituted in place of the measured alkalinity values, the resulting comparison of sums of anions versus cations no longer shows an excess of anions (Figure 5). Instead, some of the lakes show a slight anion deficit which is consistent with previous observations in natural surface waters (Baker et al. 1990). The reason for the slight anion deficits is that organic anions (results for dissolved organic carbon are currently unavailable) are presently unaccounted for in the sums of anions. Therefore, the calculated alkalinity values appear to be a slightly more accurate representation of alkalinity than are the titrated alkalinity values. One notable exception is for Little Twin Lake where the calculated alkalinity (C_B - C_A) is 13 μeq/L, yet the measured alkalinity is -5 μeq/L. Alkalinity calculated using pH is -10 μeq/L, suggesting that there may be a slight overestimate of base cations or an underestimate of sulfate. Because the calculated conductivity values for both Big

Table 3. Quality control reference samples analyzed concurrently with the Umpqua National Forest lake samples. All units are in μeq/L except for pH (s.u.) and silica (mg/L as SiO_2). AN represents Forest Service laboratory results; CERT represents certified values; MPV represents most probable value.

					USGS							
	Canada		EPA		P15		M114		T111		N27	
	AN	CERT	AN	CERT	AN	MPV	AN	MPV	AN	MPV	AN	MPV
pH	-	-	6.00	6.00	5.49	5.50	7.84	7.67	-	-	-	-
Ca^{2+}	1432	1253	-	-	21.5	19.0	719	719	1018	1013	-	-
Mg^{2+}	472	493	-	-	5.8	5.8	296	296	486	491	-	-
Na^+	461	452			40.0	39.2	1840	1831	-	-	-	-
K^+	35.8	33.2	-	-	5.1	4.9	-	-	-	-	-	-
Cl^-	-	-	-	-	-	-	1645	1546	-	-	22.6	24.8
NO_3^-	-	-	-	-	-	-	-	-	-	-	18.2	18.9
SO_4^{2-}	-	-	-	-	21.9	21.4	-	-	-	-	-	-
HCO_3^-	-	-	-	-	41.3	39.0	-	-	-	-	-	-
SiO_2	-	-	-	-	-	-	11.0	10.9	9.9	9.8	-	-

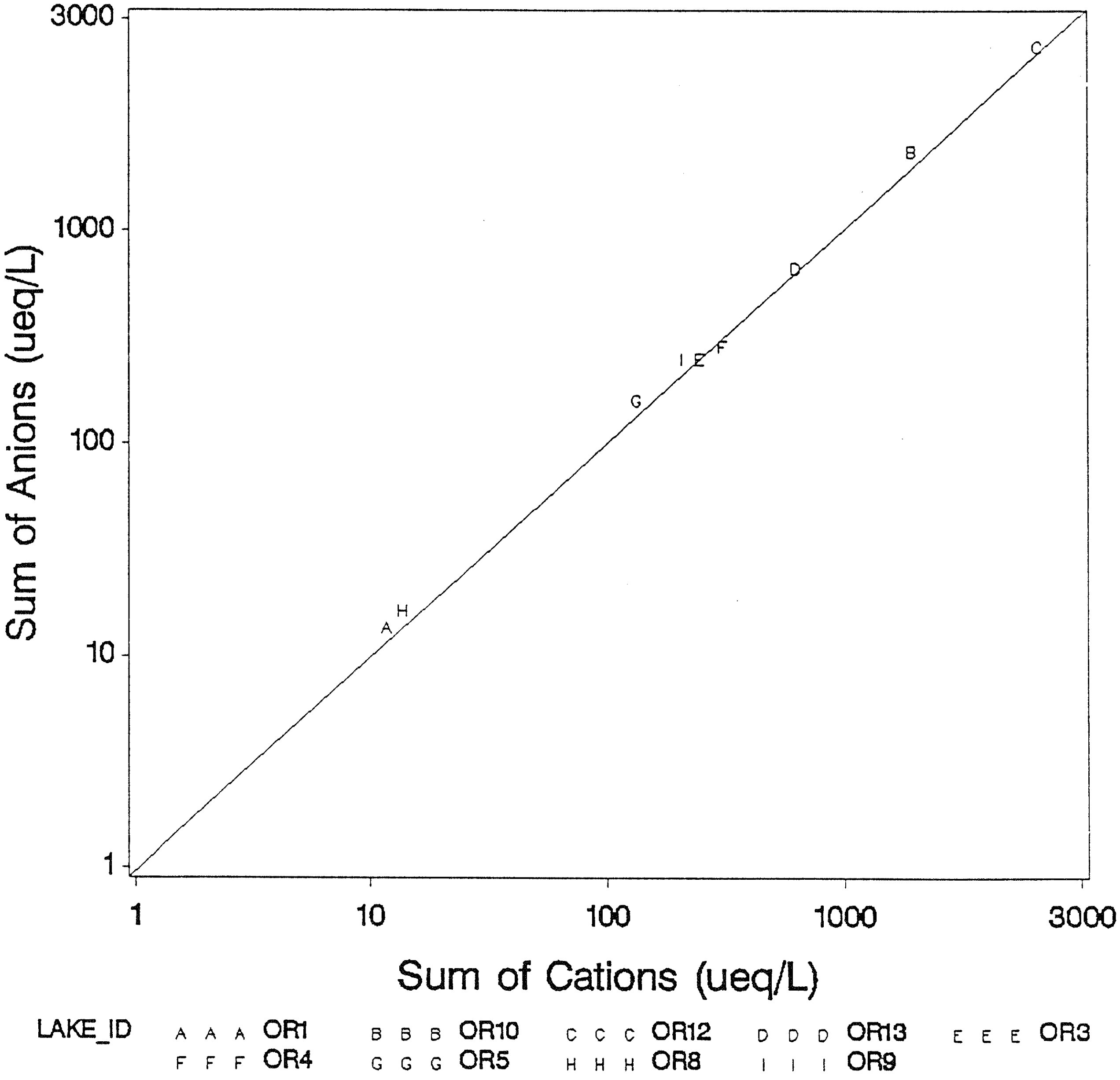


Figure 4. Sums of anions (Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-) plotted against sums of cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, H^+) for the study lakes. Values for HCO_3^- are based on measured alkalinity. Units are in μeq/L. Lake codes are shown in Figure 1 and Table 4.

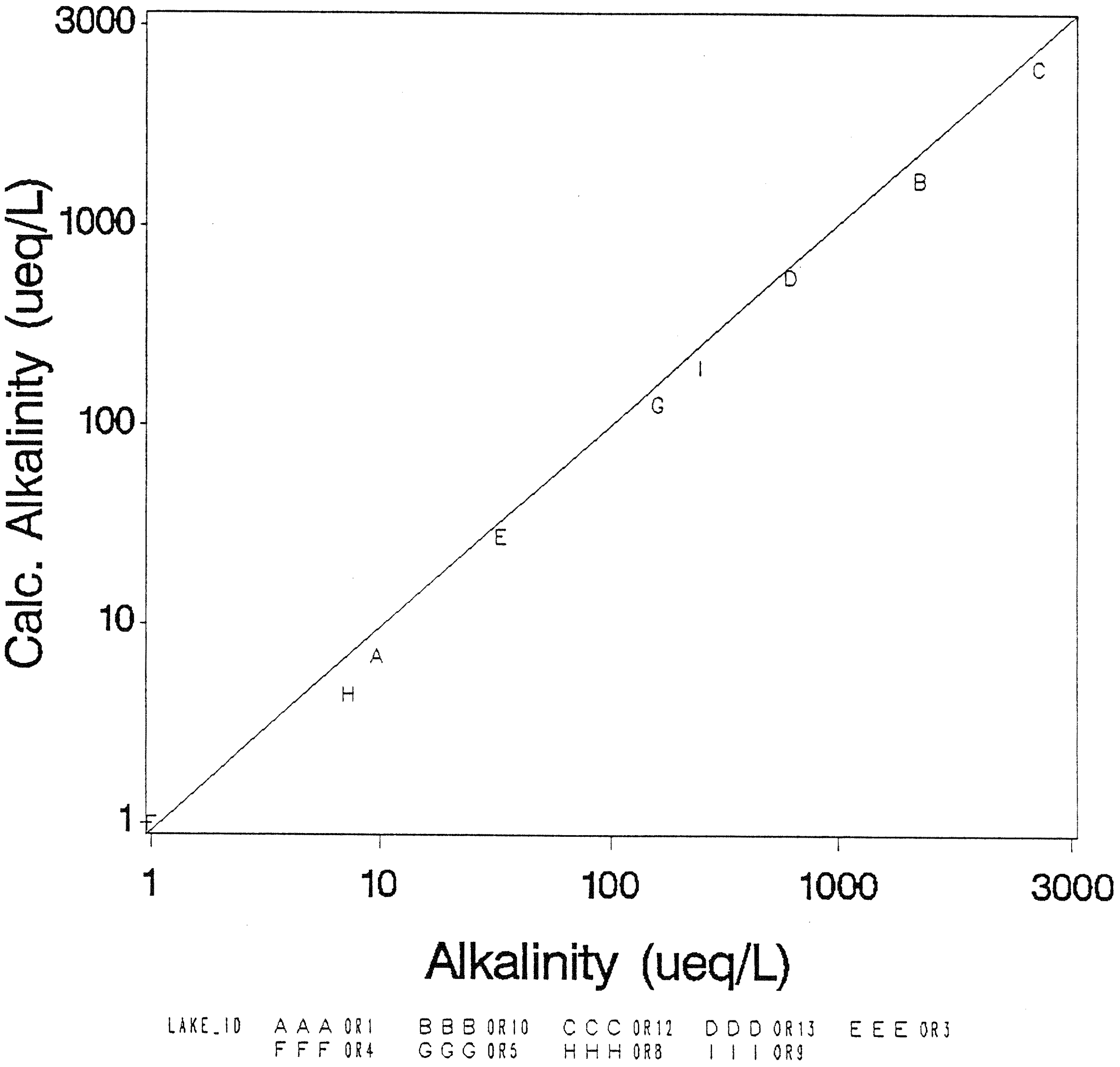


Figure 5. Calculated alkalinity plotted against measured alkalinity for the study lakes. Calculated and measured alkalinity for Little Twin Lake are -6 μeq/L and -5 μeq/L, respectively; however, the data point is plotted at the origin of the plot to avoid problems with scaling of the axes. Calculated alkalinity is based on $[Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}] - [SO_4^{2-} + Cl^{-} + NO_3^{-}]$. Units are in μeq/L.

Twin and Little Twin Lakes are lower than measured values suggests that the discrepancy is associated with an underestimate of one or more ions, in this case sulfate. A further review of the sulfate data showed that the concentration of 288 μeq/L was computed based on peak height measurements from the ion chromatograph. The peak for this sample was unusually flat and sulfate was recomputed based on the area under the curve. The revised sulfate value is 307 μeq/L, which results in agreement between calculated alkalinity (-6 μeq/L) and hydrogen ion; this latter sulfate value was used in the data analysis.

Two samples were identified as highly unusual based on pattern recognition analysis: magnesium for OR1 and silica for OR9. The results for both values were rechecked by the laboratory and found to be correct. Magnesium for OR1 was run in duplicate (both values measured at 0.00 pm or < 0.4 μeq/L on the ICP, and one analysis of 0.007 ppm [0.6 μeq/L] on the AA). The silica for OR9 was run twice on the ICP with nearly identical results (Si = 8.74 and 8.90 mg/L [SiO_2 = 18.5 and 18.9]).

In summary, the quality assurance review of the data indicates that the data are of good quality. No substantive problems were noted with contamination, precision, or bias. However, one duplicate sample was rejected based on minor discrepancies in the anions, and calculated alkalinity is reported in lieu of the measured alkalinity values. The edited data and the associated computer files are presented in Appendix C.

C. Lake Chemistry

Major ion chemistry for the study lakes is presented in Table 4 and is graphically represented in Figure 6 as ion bar charts. Seven of the study lakes are primarily bicarbonate waters. Most of the lakes are dominated by calcium, although sodium and magnesium are important ions in the dilute waters. Nitrate is virtually absent in the lakes and contributions of chloride are fairly uniform, but low. In the hardwater lakes (Fish, Buckeye, Cliff), contributions of sulfate and potassium are substantially greater than the more dilute lakes, although on a

Table 4. Chemistry of study lakes in the Umpqua National Forest. The raw data reported from the laboratory (Appendix B) have been modified as follows: (1) the duplicate samples for Cliff Lake (OR10 and OR11) have been averaged; (2) the duplicate for Lucille Lake (OR7) has been omitted; and (3) the peak-height SO_4^{2-} value for Little Twin Lake (OR4) has been substituted with the integrated area SO_4^{2-} value.

				Major Ions												
Lake Name	Lab ID	pH	Conduct. (μS/cm)	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	ΣCations	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-[a]	ΣAnions[b]	$C_B - C_A$[c]	SiO_2 mg/L
				μeq/L												
Calumet	OR1	5.90	2.9	1.8	0	7.5	1.9	0.6	11.7	4.1	0	0	9.7	13.8	7.1	1.3
Big Twin	OR3	6.29	39.5	140.7	56.1	47.9	4.1	0	248.8	9.7	0	211.3	33.7	254.8	27.7	8.3
Little Twin	OR4	5.00	51.3	163.2	74.8	66.6	5.3	0	309.8	8.8	0	307.0	-5.2	291.7	-6.0	12.1
Skookum	0R5	7.16	15.5	58.9	34.0	32.2	7.3	0	132.4	1.7	0	0	160.6	162.3	130.6	4.7
Lucille	0R8	5.91	3.1	2.9	1.7	7.2	1.8	0	13.6	4.2	0	4.9	7.3	16.4	4.5	0.5
Maidu	OR9	7.43	28.7	81.3	33.9	62.6	28.8	0.8	207.5	6.6	0	0.5	248.1	255.2	199.6	18.7
Cliff	OR10	8.17	131.4	541.4	529.1	251.4	40.3	0.9	1363.1	4.4	0	57.1	1458.4	1519.8	1300.8	16.4
Buckeye	OR12	7.88	265.1	968.1	1267.2	149.2	74.2	2.9	2461.6	10.8	0.3	44.6	2556.3	2612.0	2403.0	19.5
Fish	OR13	7.71	66.9	430.6	109.4	84.8	4.4	0.3	629.6	8.9	0	51.4	618.3	678.7	629.2	12.0

[a] Gran alkalinity

[b] PO_4^{2-} is not shown. All values were less than the detection limit with the exceptions of Maidu Lake (0.05 μeq/L) and Buckeye Lake (0.03 μeq/L).

[c] Calculated alkalinity

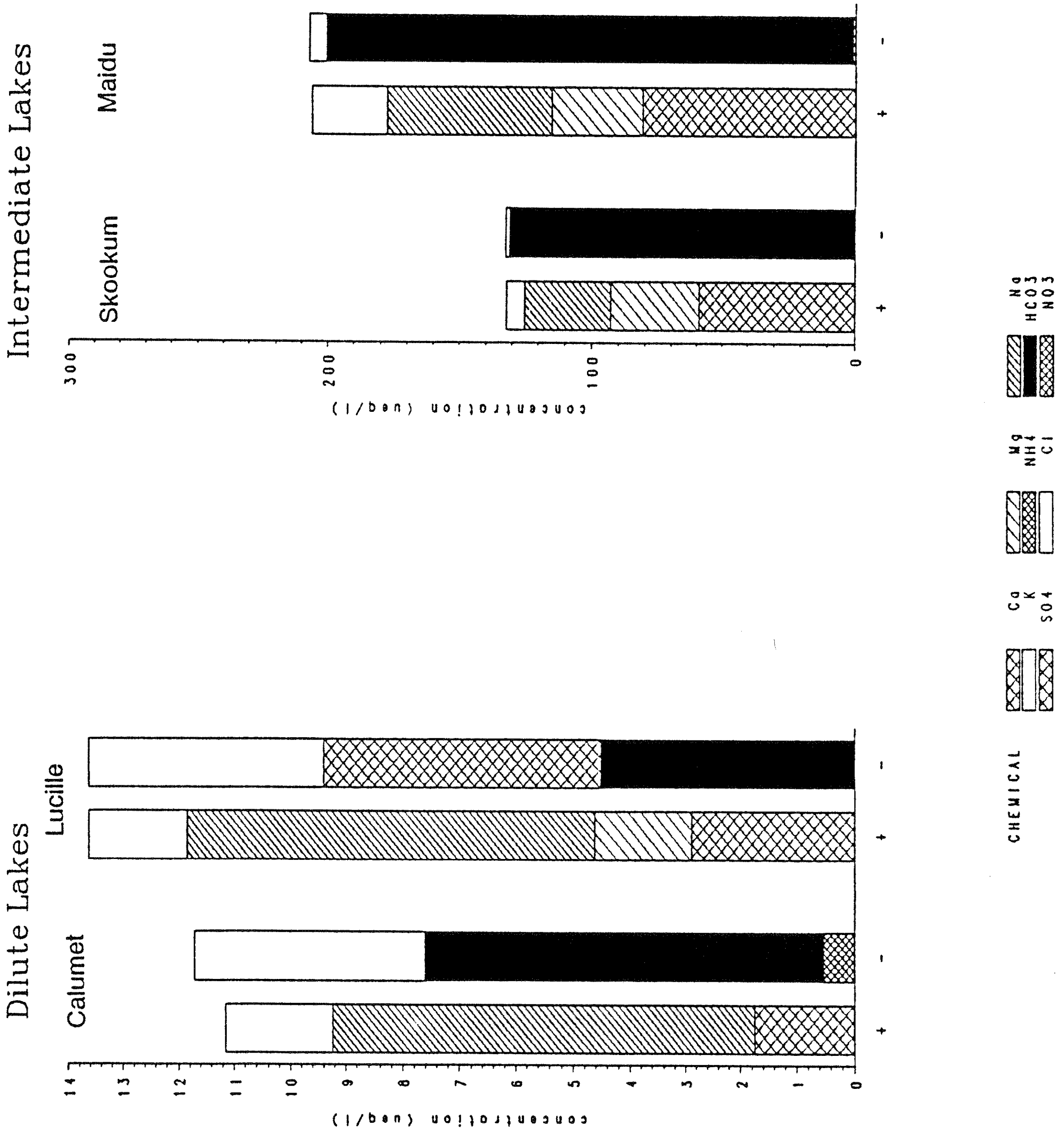


Figure 6. Ionic composition of the study lakes represented as bar charts. The cations are summed on the left, the anions on the right. Because of the large range in ionic concentrations, the lakes have been grouped into four groups of similar ionic values (note the different scales for each group).

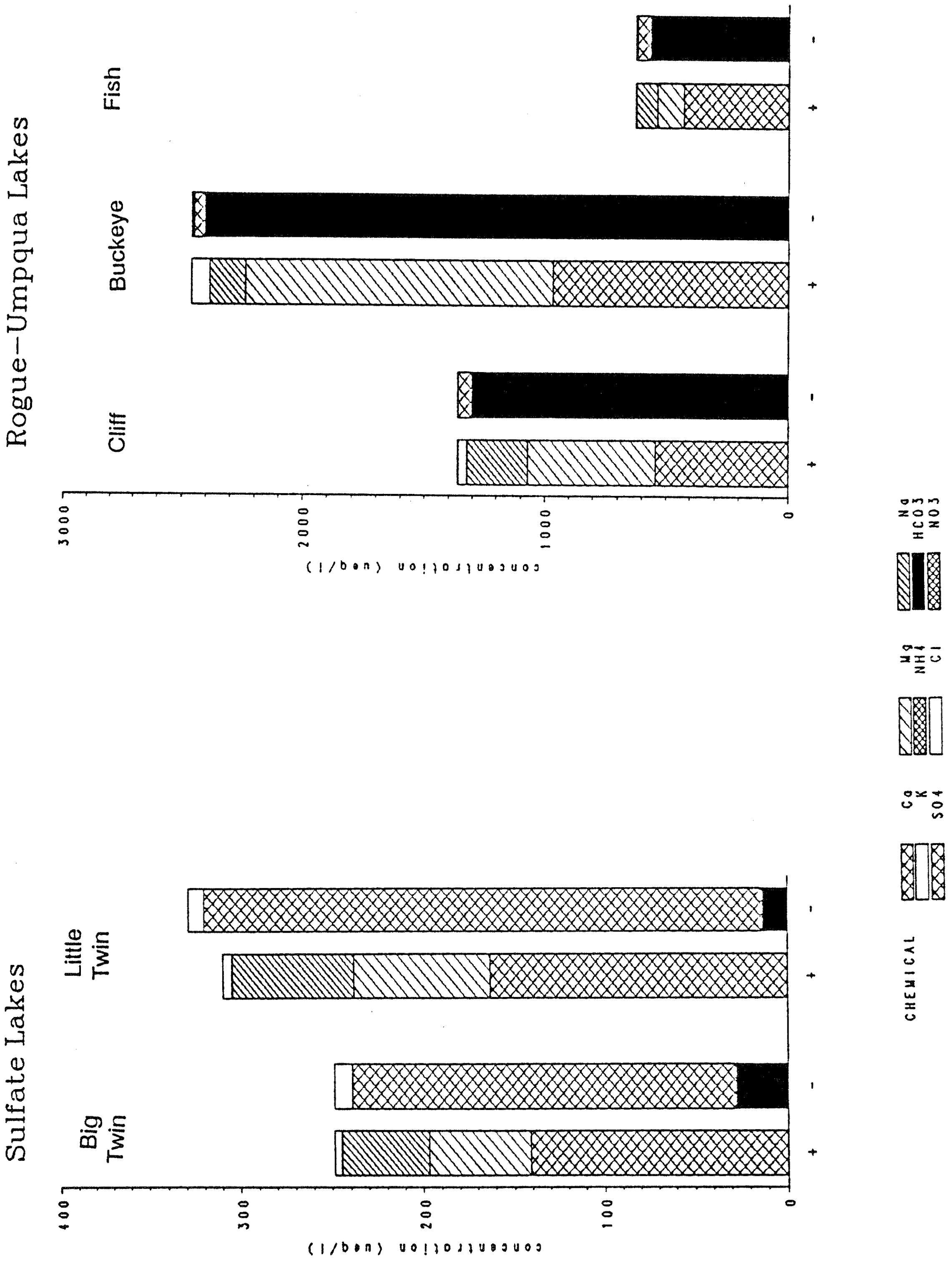


Figure 6. Continued

percentage basis, their concentrations are relatively unimportant. Two lakes (Big and Little Twin) stand out as being radically different from the other study lakes in that sulfate concentrations are very high and bicarbonate is low. Measured and calculated alkalinity in Little Twin are negative, the pH is 5.00 (H^+ = 10 μeq/L), further indication of its slightly acidic status.

The relative ion composition of the samples shows a considerable diversity in major ion chemistry for these study lakes (Figure 7). Unlike most lakes in the Cascades which are predominantly $[Ca^{2+} + Mg]^{2+}]$ bicarbonate systems (Landers et al. 1987), Lakes Lucille and Calumet have more sodium than all other cations combined. Interestingly, Calumet Lake contains no measurable magnesium (± 2 μeq/L). In the two highest solute lakes, Cliff and Buckeye, magnesium equalled or exceeded calcium. With respect to anion composition, Big and Little Twin Lakes are clearly distinct in being dominated by sulfate.

The study lakes also exhibit a tremendous range in total solute concentrations ranging from total ion concentrations of 25 and 30 μeq/L, (Calumet and Lucille Lakes, respectively), up to 5074 μeq/L for Buckeye Lake. Measured conductivity values vary in a similar manner from 2.9 and 3.1 μS/cm to 265 μS/cm for the same three lakes. The high transparency and lack of substantial anion deficits indicate that organic acids are unimportant in assessing the acid-base status of these lakes.

IV. DISCUSSION

A. Comparison of Lake Chemistry to Results from the Western Lake Survey

Unlike this study, EPA's Western Lake Survey (WLS) was a probability sampling that quantitatively characterized the lakes in mountainous areas of the West. Nevertheless, the results from this modest study can be placed in the context of the WLS to determine how similar these lakes are to those sampled in the probability survey. Region 4B of the WLS includes lakes located primarily in the Oregon and Washington Cascades and this region is used as a basis for comparison with the nine study lakes from the Umpqua National Forest (UNF). The individual

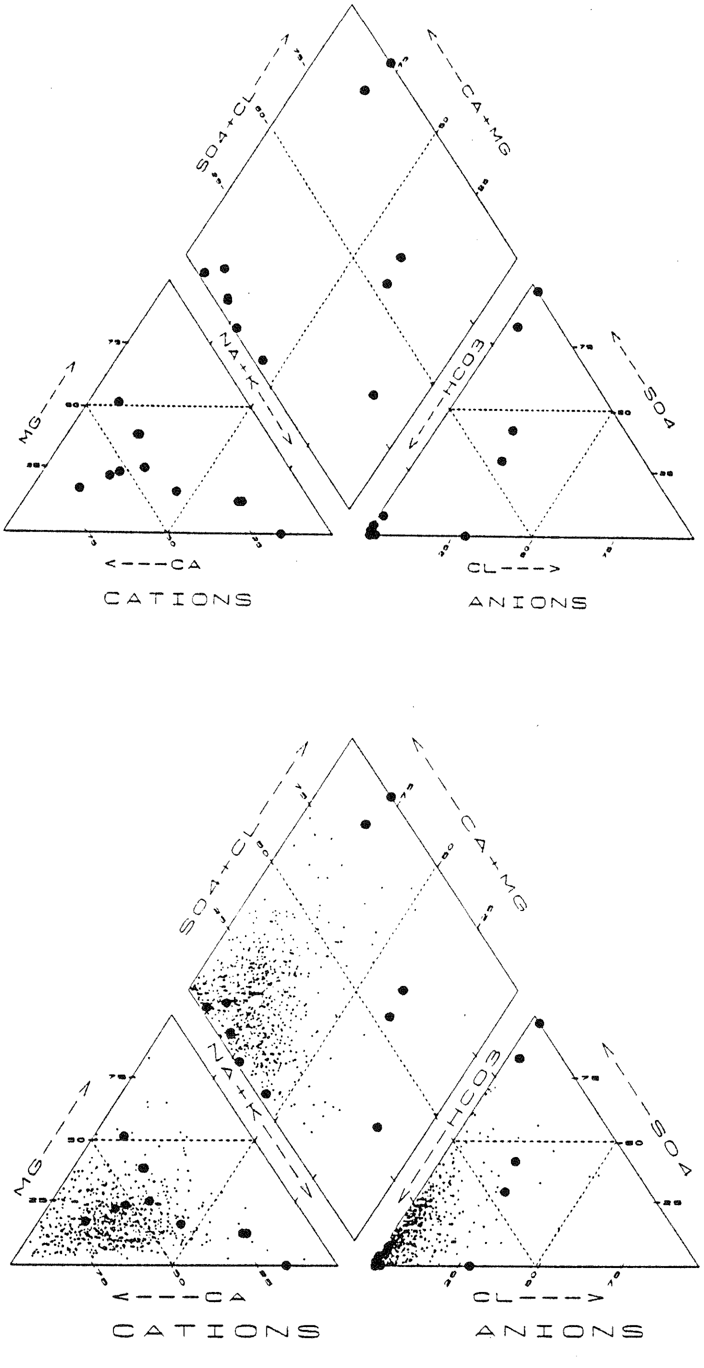


Figure 7. Relative ion composition of the study lakes shown as trilinear diagrams (a). The ratios on the axes are expressed as percent of cation or anion composition, increasing from 0 to 100 in the direction of the arrows. Minor ions such as NO_3^-, NH_4^+ and H^+ are not considered. The study lakes superimposed on lakes in subregion 4B of the Western Lake Survey are shown in (b).

lake results from the UNF have been superimposed over the cumulative frequency distributions for the specified subpopulation of WLS lakes (Figure 8) as shown in Eilers et al. (1987a). The results show that the lakes sampled in the UNF span (and occasionally exceed) the range of values measured in the Pacific Northwest Region of the WLS. Of particular note is the pH value for Little Twin Lake (5.00), which is lower than any other lake measured by WLS in the Pacific Northwest (one WLS lake sampled in Yellowstone Park, Fern Lake, was also acidic and had chemistry similar to Little Twin Lake). However, even the alkalinity values for Lakes Calumet and Lucille are low in comparison to results from WLS. The base cation (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) concentrations (and conductivity) of these two lakes are also extremely low and rank among the lowest observed to date (Eilers et al. 1990).

B. Comparison of Lake Data to Results from the U.S. Geological Survey

Eight of the nine study lakes were previously sampled by the U.S. Geological Survey in 1977-78 as part of a survey of Douglas County lakes (Rinella 1979). The USGS study provided valuable information on lake bathymetry and general lake features. The chemical characteristics of the USGS survey was generally limited to an abbreviated list of parameters; those in common with this study are shown in Table 5. The Secchi disk measurements conducted by USGS are generally greater than or equal to values measured in this study. The two largest differences occur on Big Twin Lake where the USGS located over the deepest area of the lake and in Fish Lake. The difference in Secchi disk values of over 4 m (30% less in transparency) suggests that a real decline in transparency may have occurred. Declines in lake transparency are often associated with increases in nutrient status and phytoplankton density.

Alkalinity values, particularly for the lakes with values less than 100 μeq/L show major differences between this study and the USGS study. However, most of these differences can be attributed to the relative coarse single-endpoint titration (pH 4.5 endpoint) used in the older study

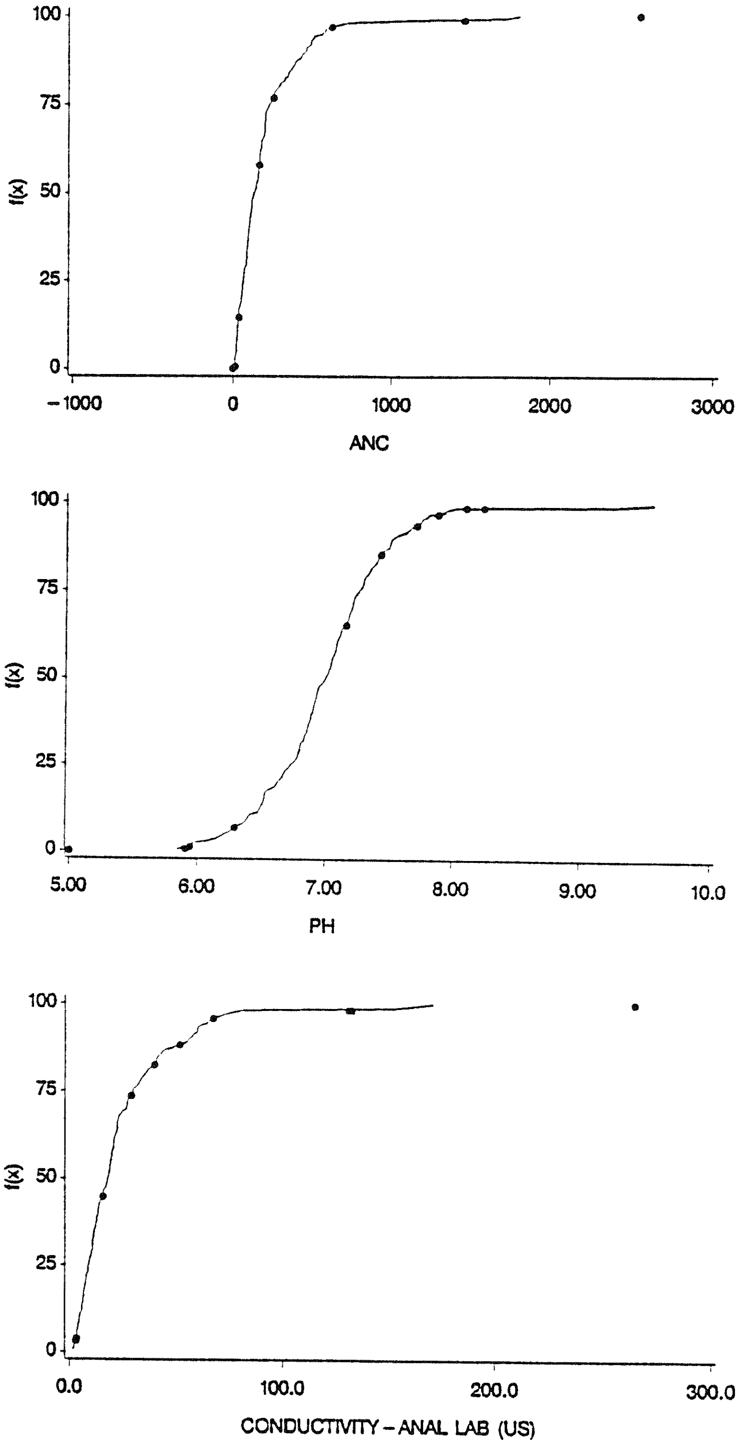
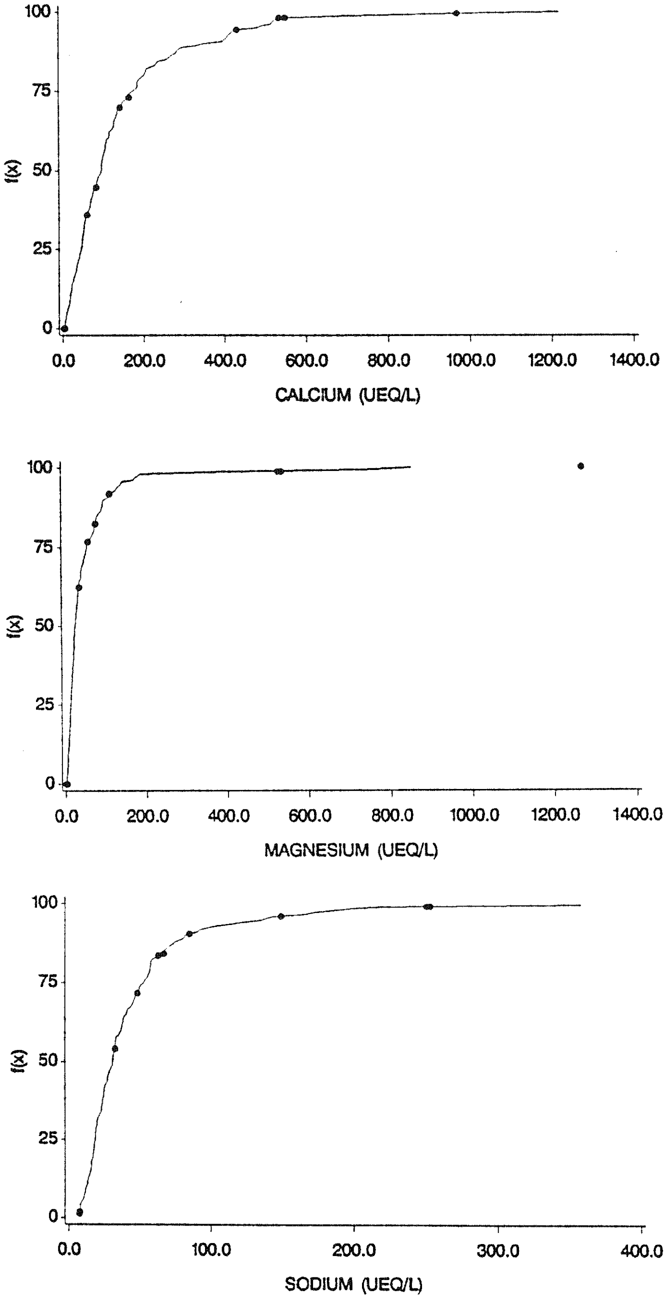


Figure 8. Cumulative frequency distributions [f(x) as a percent] for lakes in subregion 4B (Pacific Northwest) from EPA's Western Lake Survey (solid line) compared to observations from the individual lakes sampled in the Umpqua National Forest (dots). The maximum and minimum values sampled in this subpopulation of WLS are represented as the terminal points on the distributions. Other values, such as the median, can be read by extending a horizontal line from 50 (i.e. 50th percentile) on the y axis across to the f(x) curve and then extending a vertical line to the concentration on the x axis. Plots with fewer than nine Umpqua lakes (•) contain observations below the detection limits. ANC is an abbreviation for acid neutralizing capacity which is equivalent to the term "alkalinity."



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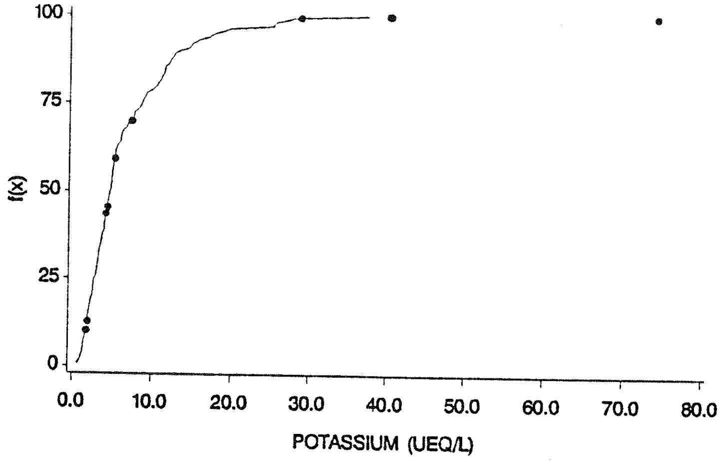

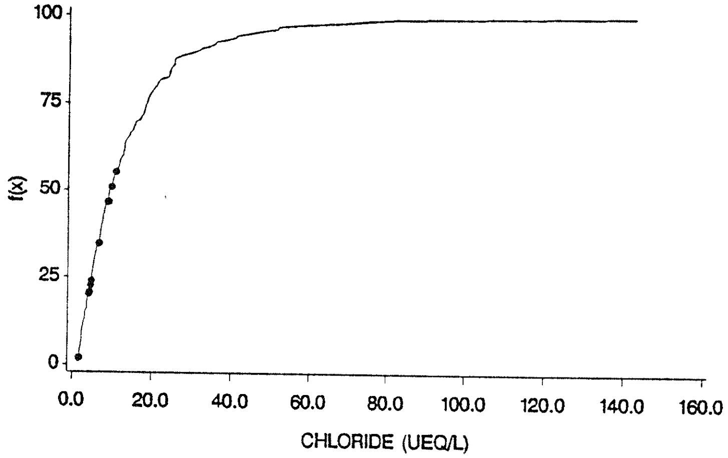

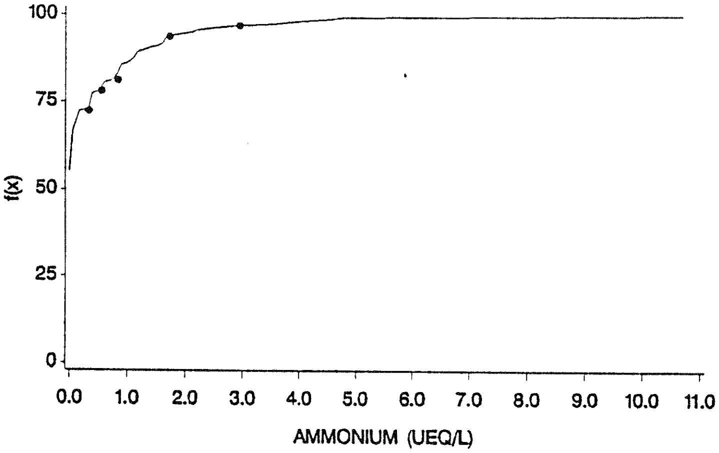

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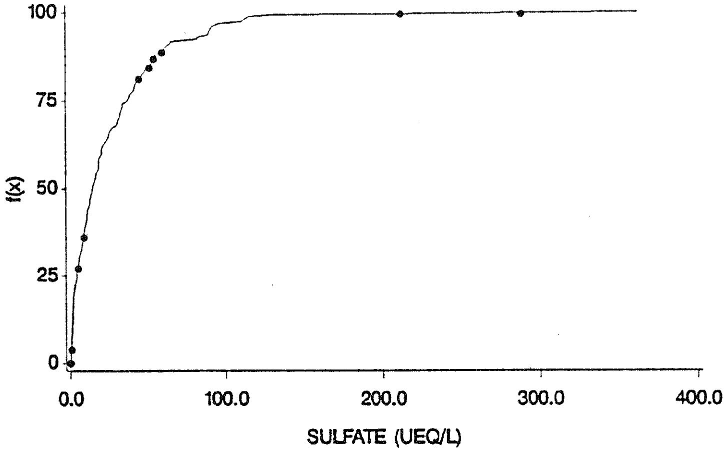

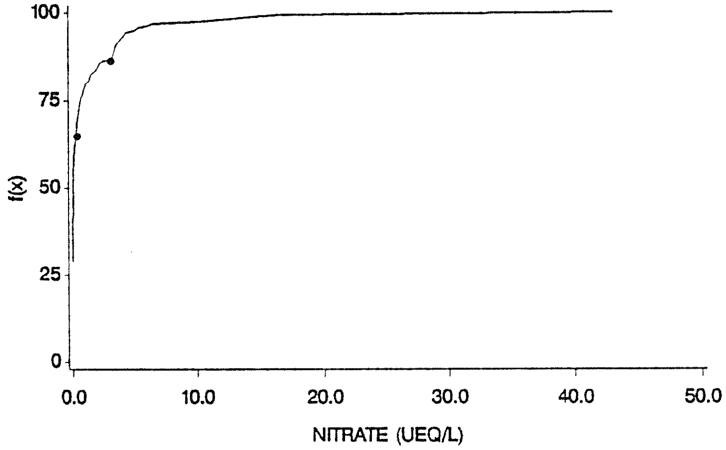

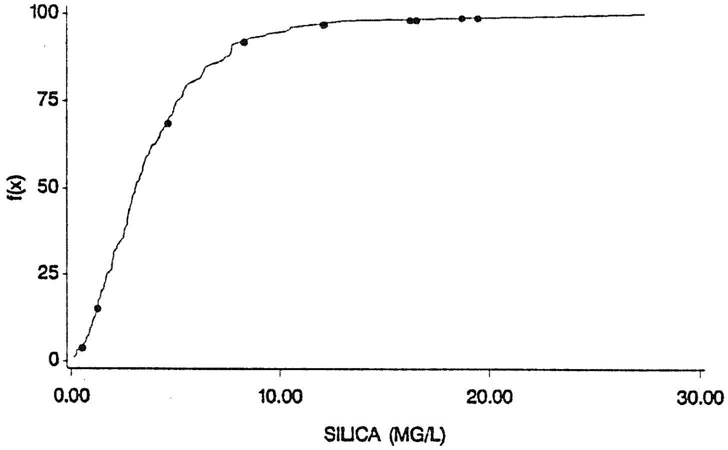

Figure 8. Continued

Table 5. Comparison of chemical and physical lake and watershed characteristics measured by the USGS study (Rinella 1979) and this study (shown below).

Lake	Color (pcu)	Secchi Disk (m)	Alkalinity (μeq/L)	pH	Conductivity (μS/cm)	Watershed Area (ha)	Lake Area (ha)
Calumet	5	7.0	100	5.8	2	114	7.3
	-	6.5_b	7	5.9	2.9	105.3	6.5
Big Twin (East)	0	15.2	60	5.6	36	85	5.7
	-	11.4_b	28	6.3	39.5	73.4	5.8
Little Twin (West)	0	9.1_b	20	4.6	47	34	2.4
	-	8.9_b	-6	5.0	51.3	33.9	2.5
Skookum	5	6.1_b	140	6.6	11	26	4.0
	-	4.4_b	131	7.2	15.5	23.0	4.6
Lucille	0	4.9_b	20	5.4	3	238	3.6
	-	4.3_b	5	5.9	3.1	40.5	3.3
Maidu	0	3.7_b	200	6.8	20	282	8.1
	-	3.1_b	200	7.4	28.7	361.2	7.8
Buckeye	5	7.9	2400	7.3	220	54	4.4
	-	8.0	2403	7.9	265	87.6	4.1
Fish	0	12.1	520	7.4	70	1920	39
	-	7.9	569	7.7	66.9	1747	37.9

b = bottom

compared to the more accurate Gran titration and calculated alkalinity (C_B - C_A) used in this study. The USGS pH values are systematically lower (x = 0.5 pH units) than values measured in this study. This can probably be attributed to significant advances in the quality of probes used for measuring pH. Conductivity values show reasonable agreement between the two studies, although the laboratory instrument used in this study is probably more accurate than field conductivity instruments used in both studies.

The watershed and lake areas were remeasured as part of this study on 1:24,000-scale USGS topographic maps. The measurements by the USGS were likely made on the older, more generalized 1:62,500-scale maps. We recommend use of the more recent measurements in all cases.

Samples were collected by the USGS for more detailed chemical analyses of Fish and Buckeye Lakes. The samples were collected at the same time of year as the samples for this study, but the USGS samples were collected from considerable depth, whereas this study collected samples from 1.5 m depth. It is likely that samples for both Fish and Buckeye Lakes collected by USGS were taken from the hypolimnion (i.e. below the thermocline) which may account for some differences in results (Table 6). In particular, pH from hypolimnetic waters is typically lower than surface water pH because the former is depressed by higher concentrations of dissolved CO_2. The remaining parameters show relatively close agreement between the results from two USGS samples and this study.

C. Lake Groups and Relationship of Lake Chemistry to Watershed Factors

The study lakes were classified into logical groups on the basis of parameters that differed appreciably from one another (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, and SiO_2). Other parameters such as pH, alkalinity, and conductivity also differed among lakes, but they provided no additional information to the grouping because they were highly correlated with parameters already selected. The lakes were partitioned into groups using a hierarchical cluster analysis; the resulting

Table 6. Comparison of detailed chemical analyses for Fish and Buckeye Lakes sampled by the U.S. Geological Survey (Rinella 1979) and this study. Units are in μeq/L for all ions; pH (s.u.), conductivity (μS/cm), silica (mg/L SiO_2).

	Fish Lake		Buckeye Lake	
	USGS	This Study	USGS	This Study
Depth of Collection (m)	30.5	1.5	6.7	1.5
Date of Collection	9-19-78	9-20-90	9-19-78	9-20-90
pH	6.0	7.71	7.1	7.88
Alkalinity	520	569	2400	2403
Ca^{2+}	429	431	998	968
Mg^{2+}	107	109	1152	1267
Na^{+}	109	85	183	149
K^{+}	10	4	72	74
ΣCations[a]	655	629	2405	2458
HCO_3^-	520	569	2400	2403
SO_4^{2-}	73	51	92	45
Cl^-	20	9	20	11
ΣAnions[b]	613	629	2512	2469
Conductivity	62	66.9	224	265
Silica	13	12.0	23	19.4

[a] NH_4^+ not included

[b] NO_3^- and F^- not included

dendogram depicting the dissimilarity among lakes is shown in Figure 9. The lakes separate very clearly along a softwater-hardwater continuum with Calumet and Lucille being extremely dissimilar from Buckeye Lake. Three pairs of lakes are evident in the cluster analysis and are termed the "dilute" group (Calumet and Lucille), the "intermediate" group (Skookum and Maidu), and the "sulfate" group (Big and Little Twin). Fish, Cliff, and Buckeye Lakes are much higher alkalinity lakes (C_B = 570, 1300, and 2400 μeq/L, respectively) and are considered collectively as the "hardwater" group.

The chemical composition of the study lakes reflects major differences in key watershed processes. Big and Little Twin Lakes undoubtedly contain watershed sources of sulfur which are reflected in the high concentrations of sulfate. The sulfur could be derived from one of several mechanisms (not stoichiometrically balanced) as shown below:

(1) $CaSO_4 + H_2O \text{ ---> } Ca^{2+} + SO_4^{2-} + H_2O$
(anhydrite)

(2) $CaSO_4 \bullet 2\,H_2O \text{ ---> } Ca^{2+} + SO_4^{2-} + H_2O$
(gypsum)

(3) $X_mS_n + O_2 + H_2O \text{ ---> } X + SO_4^{2-} + H^+$ (where X = Fe, Zn, Cu, Hg, etc.)
(sulfide ore)

(4) $S + H_2O \text{ ---> } SO_4^{2-} + H^+$
(sulfur crystals)

(5) $SO_4^{2-} + H_2O \text{ ---> } SO_4^{2-} + H^+$
(atmospheric deposition)

The geology of these two watersheds is comprised of Tertiary andesites (Sherrod and Smith 1989) and it is highly unlikely that anhydrite or gypsum are present in any significant quantities. The sulfate could not be derived from atmospheric sources because of the low ambient concentrations measured at NADP/NTN monitoring stations in Oregon (NADP/NTN 1989). The

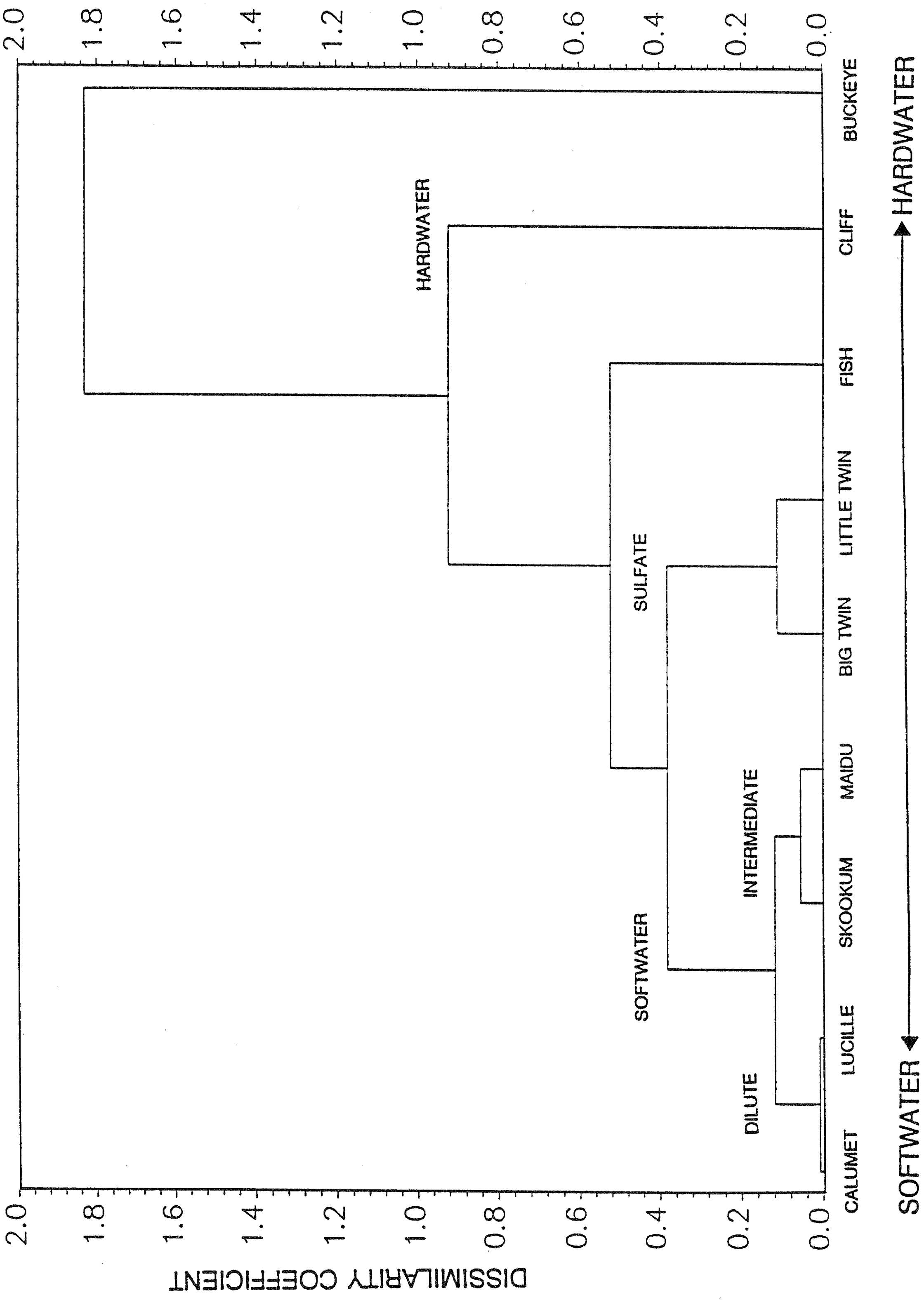

Figure 9. Dendrogram produced from average-linkage hierarchical cluster anlaysis (SAS 1988) for the nine study lakes using calcium, magnesium, sodium, potassium, sulfate, and silica as input variables. Groups of lakes with similar attributes are designated above the related lakes.

most probable sources of sulfate are from weathering and oxidation of either sulfide ores (e.g. copper, zinc, iron, mercury) or dissolution of sulfur deposits. The presence of sulfur crystals has been noted in soil investigations for the area (M. Jones, 1990, personal communication) which is consistent with mechanism (4) noted above. If this is the case, the factor governing whether the lake becomes acidic is determined by the degree of base cation production in the watershed; where base cation production exceeds sulfur inputs such as in Big Twin Lake, the lake remains alkaline, but where base cation production is lower as in Little Twin Lake, sulfur exceeds the bases and mineral acidity (sulfuric acid) is present. The acidity of Little Twin Lake may also contribute to its aqua color by increasing metal solubility and retaining small quantities of metals in solution. However, any metals in solution were below the detection limits of the ICP analyses (e.g. the detection limit for copper = 12 ppb).

The hardwater lakes (Fish, Buckeye, and Cliff) are located in watersheds containing more weatherable material not present in the watersheds of the other study lakes. These three watersheds contain Tertiary intrusives of unspecified composition (Sherrod and Smith 1989). However, the high magnesium concentrations in Cliff and Buckeye lakes are often indicative of more mafic rock types in the watersheds (Drever 1982). The lower solute concentrations (particularly magnesium) in Fish Lake indicates that the more weatherable material is localized in the vicinity of Cliff Lake and that contributions from the Cliff Lake watershed are considerably different than inputs in the northern and eastern portions of Fish Lake watershed.

The chemistry of Lucille and Calumet Lakes is dominated by precipitation chemistry with slight modifications caused by evapoconcentration, weathering, and in-lake processes. The major cation in both lakes is sodium which is derived in roughly equal proportions from precipitation and weathering (assuming all Cl^- is of marine origin). The extremely small concentrations of base cations and silica in these lakes highlights the lack of a strong connection between their topographic watersheds and the lake chemistry. It is likely that their actual watersheds (i.e. contributing area) do not extend far beyond their respective lake areas. This is consistent with hydrologic flowpaths observed for dilute lakes in other areas of the country (Baker et al. 1990). The absence of watershed runoff to Lucille Lake is consistent with the low topographic relief in the immediate area and deep, highly permeable pumice deposits adjacent to the lake. However, these results are surprising for Calumet Lake which is located more than 430 m (1430 ft) below Sawtooth Mountain. Apparently, the flowpaths adjacent to the lake have a strong vertical component causing groundwater to travel downward instead of laterally to the lake.

Skookum and Maidu Lakes have concentrations of major ions intermediate between those in the "precipitation-dominated" group (Calumet and Lucille) and the "sulfate" group (Big and Little Twin). Even though Maidu Lake has only 36% more total ion concentration than Skookum Lake, it has nearly twice as much sodium and four times as much potassium, chloride, and silica. If the lake chemistries are controlled by weathering of similar watershed minerals, the lakes should exhibit proportionately similar concentrations of silica and base cations. Most of the study lakes do show similar proportions of $SiO_2:C_B$, the major exception being Maidu Lake which receives relatively few base cations compared to silica (Figure 10). Big Twin and Little Twin Lakes also show somewhat elevated $SiO_2:C_B$, probably because of increased dissolution of the silica from sulfuric acid production. Clearly, the mineralogies in Maidu and Skookum watersheds are quite different from one another, yet the resulting alkalinity values in these two lakes are similar. If the topographic watersheds for Skookum and Maidu Lakes are representative of the surface and groundwater contributions, the lake chemistries suggests that water is moving through Skookum Lake relatively quickly, which is consistent with the high relief in the drainage area. Conversely, the contributing area to Maidu Lake appears to be a much larger, lower relief basin possibly resulting in longer contact time with the soils and bedrock.

D. Implications for Lake Management

The chemical results from these nine lakes have important implications for management of the aquatic resources in the Umpqua National Forest. Two lakes, Calumet and Lucille, are

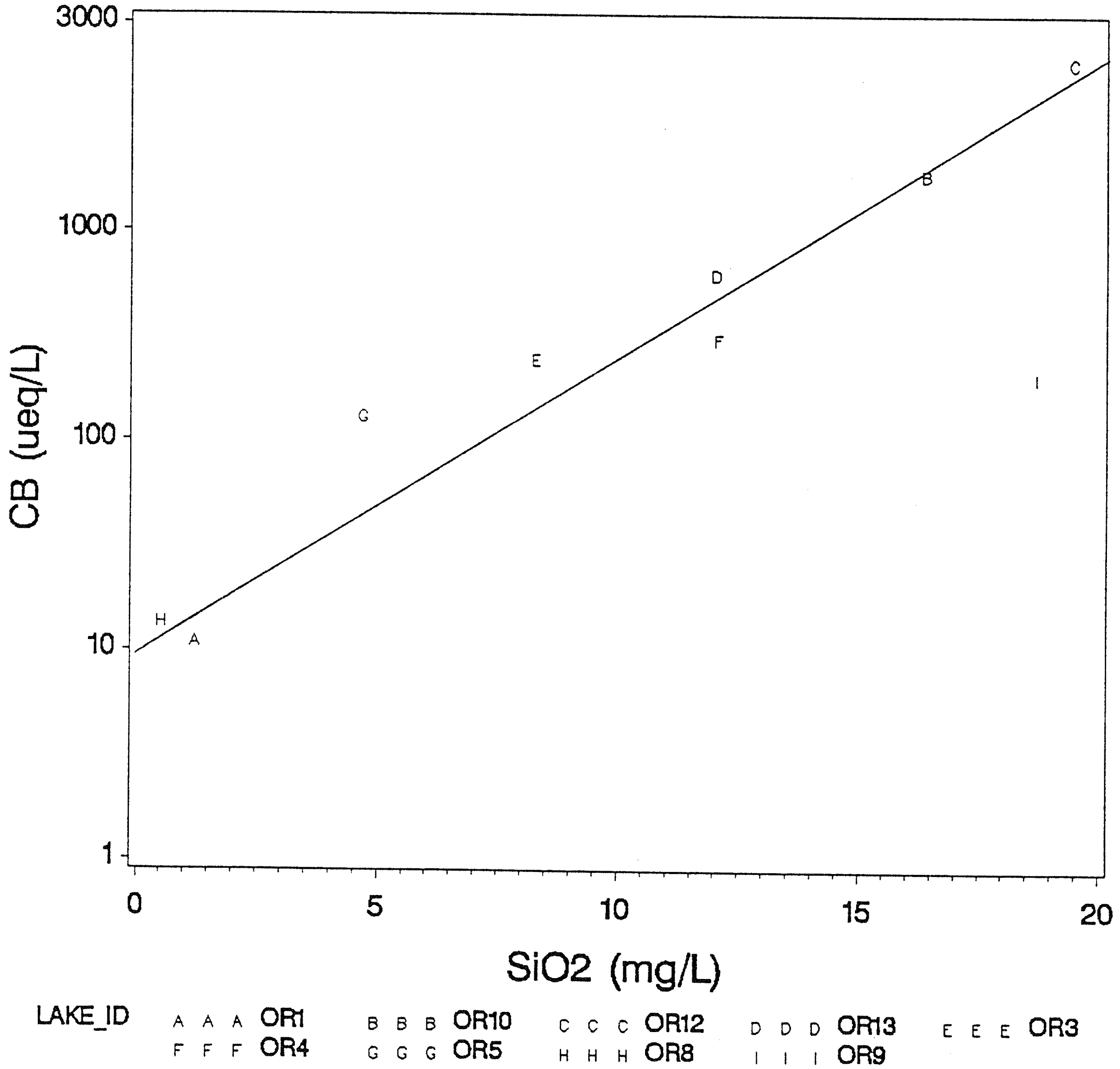

Figure 10. Lake water concentrations of silica (mg/L) versus $\log_{10}$ base cations (C_B; μeq/L) for the study lakes. Lake codes are shown in Figure 1 and Table 4. The line represents an approximate least-squares best fit.

extremely susceptible to damage from any future degradation of air quality. Both lakes have unusually low concentrations of base cations and have alkalinity values between 5 and 10 μeq/L. It is likely that the concentrations of base cations and alkalinity during the spring are about one-half of those measured in this study (Eilers et al. 1990). Therefore, relatively small additions of sulfate, nitrate, or ammonium from deposition could cause these lakes to become acidic. Should the deposition chemistry monitored at H.J. Andrews Experimental Forest (Willamette National Forest) become more acidic, it would be prudent to resume monitoring one or both of these lakes. The extremely low base cation concentrations in Calumet and Lucille make them unfavorable habitats for trout production. Lucille is currently not being stocked and Calumet should be considered for a similar management approach. Although Calumet and Lucille Lakes are among the highest elevation lakes in the Umpqua National Forest, elevation alone is a poor predictor of where other low alkalinity lakes are likely to be found (Eilers et al. 1987b).

Although Little Twin Lake is presently acidic (pH=5.00, alkalinity = -5 μeq/L), the cause of the acidity is from watershed contributions of sulfur. These contributions may be from natural flowpaths through the sulfur or may have been caused or accelerated by anthropogenic activities in the watershed. It may be useful to investigate the existence of abandoned mines or other soil disturbances that could be contributing sulfur to this lake, and to perform a conductivity survey to identify potential point-source locations of sulfur input. If a watershed reconnaissance is negative, then it can be assumed that the source of acidity is natural. The acidic waters in Little Twin Lake are also unsuitable habitat for most salmonids and this lake should be reevaluated for continued stocking of brook trout. Big Twin Lake is currently non-acidic (pH = 6.29, alkalinity ~ 30 μeq/L), although the margin between the sulfate and base cations is only about 28 μeq/L. If the sulfur loading to Big Twin Lake increases (or the base cation loading decreases), it is possible that this lake could also become acidic.

Buckeye and Cliff Lakes are naturally productive lakes as shown by their high concentrations of base cations. Both lakes exhibited very luxuriant macrophyte growth and Cliff Lake appeared to have a high phytoplankton population as well. Buckeye Lake is relatively deep and consumption of oxygen under prolonged ice cover would not likely cause any serious oxygen depletion. However, Cliff Lake is quite shallow (~ 4.3 m) and if prolonged ice cover occurs, it is likely that respiration under the ice would deplete the available oxygen and thus kill any stocked fish. Fish Lake showed a major difference in Secchi disk transparency values over an 12-year period. This could be attributed to natural variation or it may reflect an increased productivity of the lake. This apparent decline in transparency may warrant a closer examination.

The remaining lakes (Skookum, and Maidu) exhibit no obvious features that would require special management concerns at this time, although Maidu Lake does have a history of winterkill because of its shallow depth (Bauer et al. 1968).

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VI. APPENDICES

A. 35 mm transparencies of the nine Umpqua National Forest lakes sampled September 17-20, 1990. All photographs by J.M. Eilers.

B. Raw data file of the study lakes provided by the Rocky Mountain Forest Range Experiment Station, Fort Collins, CO.

C. Edited data file and floppy disk containing data in ASCII format

(i) Field data
(ii) Raw laboratory data
(iii) Edited laboratory data
(iv) Edited lab and field data in WLS-style format

Appendix B. Raw data file of the study lakes provided by the Rocky Mountain Forest Range Experiment Station, Fort Collins, CO.

FS	SOILS	SAMPLE		SAMPLE	JULIAN	RECEIVED		Measured	MG/L									UEQ/L	MG/L	MG/L	FS
ID#	LAB #	ID	DEPT	DATE	DATE	DATE	pH	Conduct.	Ca	Mg	Na	K	NH4	Cl	NO3	SO4	PO4	HCO3	SiO2	P	ID#
[Import]																					
OR1		CALUMET		09/17/90	260	09/19/90	5.90	2.93	0.04	0.00	0.17	0.08	0.01	0.15	0.00	0.00	0.00	9.70	1.25	0.01	OR1
OR2		TROUT LAKE 4		09/17/90	260	09/19/90	5.41	1.33	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.30	0.05	0.02	OR2
OR3		BIG TWIN		09/17/90	260	09/19/90	6.29	39.51	2.82	0.68	1.10	0.16	0.00	0.35	0.00	10.15	0.00	33.70	8.30	0.01	OR3
OR4		LITTLE TWIN		09/17/90	260	09/19/90	5.00	51.32	3.27	0.91	1.53	0.21	0.00	0.31	0.00	13.84	0.00	-5.20	12.09	0.02	OR4
OR5		SKOOKUM LAKE 5		09/19/90	262	09/21/90	7.16	15.54	1.18	0.41	0.74	0.29	0.00	0.06	0.00	0.00	0.00	160.60	4.69	0.01	OR5
OR6		BROOK LAKE 6		09/19/90	262	09/21/90	5.53	1.46	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.03	0.02	OR6
OR7		LUCILLE LAKE 7		09/19/90	262	09/21/90	5.94	3.12	0.06	0.02	0.16	0.07	0.00	0.17	0.19	0.41	0.21	7.20	0.50	0.01	OR7
OR8		ROUND LAKE 8		09/19/90	262	09/21/90	5.91	3.13	0.06	0.02	0.17	0.07	0.00	0.15	0.00	0.24	0.00	7.30	0.53	0.01	OR8
OR9		MAIDU LAKE 9		09/19/90	262	09/21/90	7.43	28.72	1.63	0.41	1.44	1.12	0.02	0.23	0.00	0.02	0.05	248.10	18.70	0.01	OR9
OR10		CLIFF LAKE 10		09/19/90	262	09/25/90	8.24	130.62	10.70	6.38	5.81	1.58	0.00	0.16	0.00	2.61	0.00	1461.30	16.24	0.02	OR10
OR11		DROP LAKE 11		09/19/90	262	09/25/90	8.10	132.23	11.00	6.48	5.75	1.57	0.03	0.15	0.00	2.87	0.00	1455.50	16.54	0.02	OR11
OR12		BUCKEYE LAKE 12		09/19/90	262	09/25/90	7.88	265.10	19.40	15.40	3.43	2.90	0.05	0.38	0.02	2.14	0.03	2556.30	19.45	0.01	OR12
OR13		FISH LAKE 13		09/19/90	262	09/25/90	7.71	66.87	8.63	1.33	1.95	0.17	0.01	0.32	0.00	2.47	0.00	618.30	12.03	0.01	OR13
				QA/QC																	
DI							5.48	0.67	0.00	0.00			0.00	0.00	0.00	0.00	0.00	-0.30	0.01	0.00	
CANADA-AN									28.70	5.74	10.60	1.40									
CANADA-CERT									25.10	5.99	10.40	1.30									
EPA-AN							6.00														
EPA CERT							6.00														
USGS-P15-AN							5.49		0.43	0.07	0.92	0.20				1.05		41.30		0.08	
USGS-P15-MPV							5.50		0.38	0.07	0.90	0.19				1.03		39.00		0.08	
USGS-M114-AN							7.84		14.40	3.60	42.30			58.30					11.00	0.25	
USGS-M114-MPV							7.67		14.40	3.60	42.10			54.80					10.90	0.27	
USGS-T111-AN									20.40	5.91									9.89		
USGS-T111-MPV									20.30	5.97									9.82		
USGS-N27-AN														0.80	1.13					1.08	
USGS-N27-MPV														0.88	1.17					1.07	

OA/QC Section:

FS						UEQ/L					SUM	SUM	TOTAL	%ION	SUM	SUM	DIFF=	HCO3	FLAG	% COND	FLAG	THEOR.	Si	Al
ID#	pH	CA	MG	NA	K	NH4	CL	NO3	SO4	[ANC]	ANIONS	CATIONS	ION	DIFF	BASES	ACIDS	ALK		%ION	DIFF	% COND	COND	Test	Test
OR1	0.00125	1.75	0.00	7.48	1.92	0.55	4.09	0.00	0.00	9.70	13.79	11.70	25.49	8.19	11.15	4.09	7.06	9.70	OK	-53.26	Check	1.37	OK	Below DL
OR2	0.00384	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.30	-1.30	0.35	-0.95	174.59	0.35	0.00	0.35	-1.30	Check	-102.79	Check	-0.04	Below DL	Below DL
OR3	0.00051	140.72	56.12	47.85	4.12	0.00	9.73	0.00	211.33	33.70	254.76	248.80	503.57	1.18	248.80	221.06	27.74	33.70	OK	-24.62	Check	29.78	OK	Below DL
OR4	0.00992	163.17	74.80	66.55	5.27	0.00	8.77	0.00	288.16	-5.20	291.73	309.80	601.54	-3.00	309.79	296.93	12.86	-5.20	OK	-28.87	Check	36.51	OK	Below DL
OR5	0.00007	58.88	33.98	32.19	7.31	0.00	1.72	0.00	0.00	160.60	162.32	132.37	294.69	10.16	132.37	1.72	130.65	160.60	OK	-10.69	OK	13.88	OK	Below DL
OR6	0.00293	2.25	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.30	0.30	3.16	3.46	-82.67	3.16	0.00	3.16	0.30	Check	-87.98	Check	0.18	Below DL	Below DL
OR7	0.00115	3.04	1.73	7.13	1.71	0.00	4.71	3.05	8.58	7.20	23.54	13.62	37.16	26.69	13.62	16.34	-2.72	7.20	OK	-28.98	OK	2.22	OK	Below DL
OR8	0.00123	2.89	1.73	7.22	1.79	0.00	4.23	0.00	4.89	7.30	16.42	13.63	30.06	9.28	13.63	9.12	4.51	7.30	OK	-45.73	OK	1.70	OK	Below DL
OR9	0.00004	81.34	33.90	62.64	28.75	0.83	6.57	0.00	0.50	248.10	255.17	207.46	462.63	10.31	206.62	7.07	199.55	248.10	OK	-22.16	OK	22.36	OK	Below DL
OR10	0.00001	533.93	524.99	252.72	40.41	0.00	4.54	0.00	54.34	1461.30	1520.18	1352.06	2872.24	5.85	1352.06	58.88	1293.18	1461.30	OK	3.67	OK	135.41	OK	Below DL
OR11	0.00001	548.90	533.22	250.11	40.16	1.72	4.23	0.00	59.76	1455.50	1519.49	1374.11	2893.60	5.02	1372.39	63.99	1308.41	1455.50	OK	3.36	OK	136.66	OK	Below DL
OR12	0.00001	968.06	1267.23	149.20	74.17	2.94	10.80	0.34	44.56	2556.30	2612.00	2461.60	5073.60	2.96	2458.66	55.70	2402.96	2556.30	OK	-10.33	OK	237.71	OK	Below DL
OR13	0.00002	430.64	109.44	84.82	4.35	0.33	8.94	0.00	51.43	618.30	678.67	629.58	1308.25	3.75	629.25	60.37	568.88	618.30	OK	-5.38	OK	63.27	OK	Below DL