WATER QUALITY OF SELECTED LAKES IN EASTERN SHERIDAN COUNTY MONTANA

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by JON C. REITEN
Hydrogeologist

Montana Bureau of Mines and Geology
1500 North 30th
EMC Campus Box 112
Billings, Montana 59101

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INTRODUCTION

Dozens of lakes are located in eastern Sheridan County Montana (Plate 1). Although a few individual water analysis of area lakes have been conducted, background water quality has never been analyzed or compiled for a majority of these lakes. Realizing the importance of maintaining water quality in the county, area residents proposed conducting a baseline sampling program to assess the existing lake water quality and to provide background data in the event of future impacts.

These lakes are very diverse in size, depth, water quality, and uses. The size of the lakes ranges from small unnamed ponds covering only a few acres to large lakes such as Medicine Lake covering several square miles. While most of the lakes are shallow ephemeral water bodies that are dry during extended droughts, many are deeper perennial water bodies. The deepest lake in the region is Brush Lake which is over 60 feet deep (Donovan, in press). Although very little previous work has been conducted comparing the water quality of lakes in this region, observations based on vegetation, presence or absence of deposits of sodium sulfate salts, and traditional uses all point towards a wide range of lake water quality. Uses of the lakes include stock watering, recreation, wildlife habitat, and a potential for extraction of mineral resources (glauber salts) in some of the lake basins. Many of the lakes are important to the water balance of the region both as focused recharge sources and as buffers influencing ground-water levels.

PHYSIOGRAPHY AND CLIMATE

The study area covers the eastern one-third of Sheridan County (Figure 1). This region consists of a slightly elevated generally hummocky land surface in the north and west bounded by relatively flat broad swales in the south and east. The swales are named the Clear Lake and Medicine Lake swales and appear to be associated with relict pre-Quaternary river systems. Lakes are located in both the hummocky upland areas and the relatively flat broad swales. Most of the larger lakes are located in the broad swales. Ephemeral streams such as Lake Creek occupy parts of the larger swales. Surface drainage is very poorly developed in much of the rest of the area. Typically, the individual closed-lake basins form catchments collecting runoff from the immediate surrounding area. Only under extremely high water conditions are many of these lakes physically connected by surface water. Most of the lakes have formed in topographic depressions such as kettles and meltwater channels that developed following the retreat of the last late-Wisconsinan glaciers(10,000-12,000 years B.P.).

Eastern Sheridan County has a semiarid continental climate, characterized by cold dry winters, moderately hot and dry summers, and cool dry falls. The average precipitation in Westby, near the center of the study area is about 14.2 inches per year, with about 65% of the precipitation falling from May through August (Table 1). Potential evaporation is significantly higher than precipitation. Measured evaporation from a class A pan near Froid, MT averaged 52 inches annually from 1984 to 1988. Evaporation estimated from

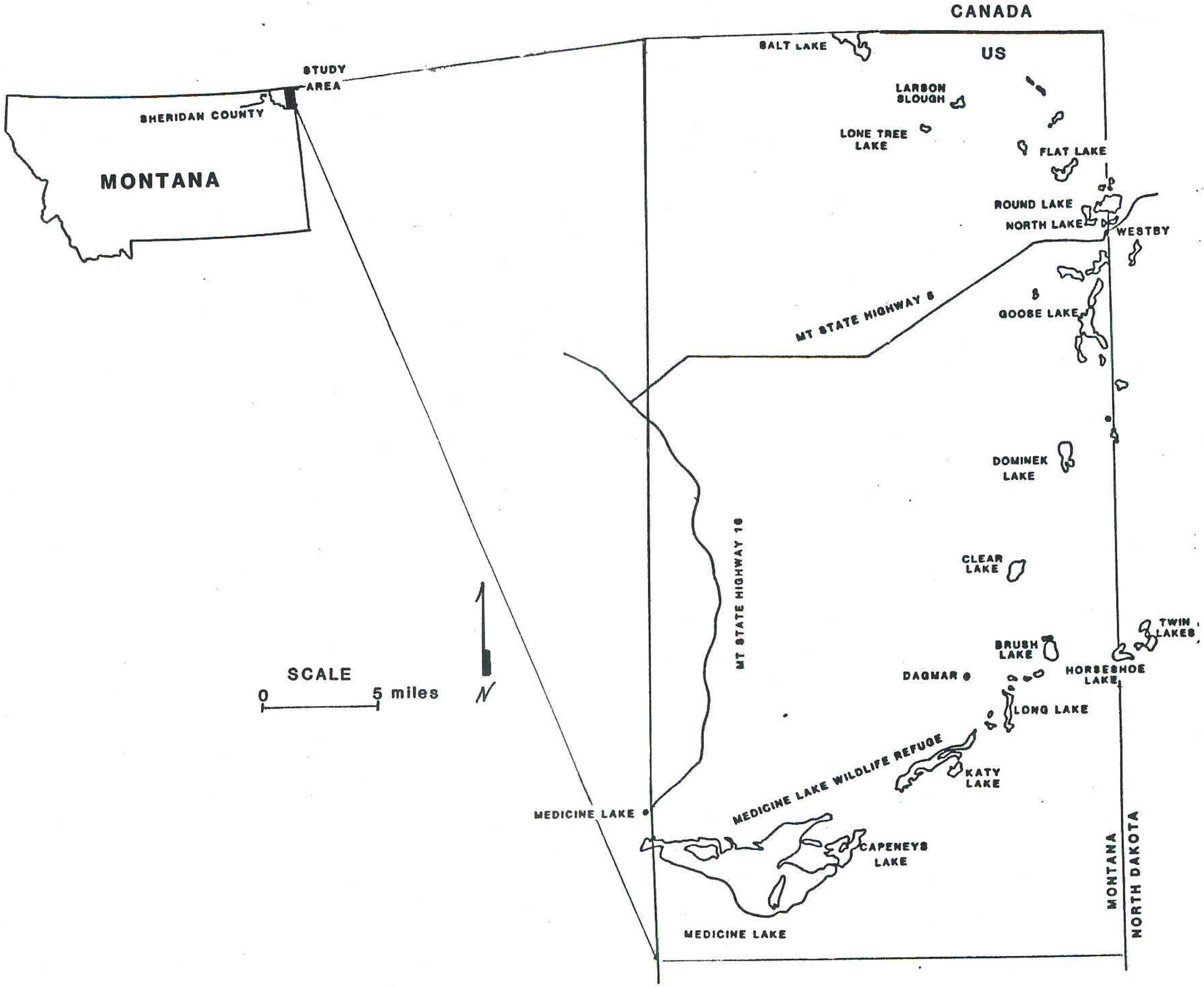

Figure 1. Location of the study area in eastern Sheridan County.

Table 1. Measured total monthly precipitation in the Westby area.
Data collected by the National Oceanic and Atmospheric Administration

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1980	.66	.31	.43	1.30	.39	2.63	1.14	4.74	1.58	1.06	.26	.55	15.05
1981	.10	.06	.38	.50	1.47	3.97	1.12	2.04	.78	.81	.81	.29	12.33
1982	1.08	.46	.85	.82	3.07	1.14	1.31	1.93	1.85	.82	0	.82	14.15
1983	.26	.07	.73	0	1.16	1.58	2.27	.88	2.00	.01	.29	.30	9.55
1984	.63	.03	.07	0	.59	3.31	.07	.29	1.25	.42	0	.22	6.88
1985*	.06	.22	.78	1.15	1.29	.93	1.02	2.35	1.25	.93	.30	.29	10.57
1986*	.25	.37	.17	.73	3.12	2.56	3.22	.49	4.97	1.41	.44	.06	17.79
1987	.15*	.12*	1.16*	.01*	2.50*	1.20*	5.17	.61	1.04	.18	.11	.01	12.26
1988	.01	.20	.40	.44	1.07	2.33	1.32	.95	1.54	.27	.43	.73	9.69
1989	1.33	.21	.39	1.38	1.30	1.89	.50	.72	.42	1.65	.24	.10	10.13
1990	.10	.01	1.23	.57	2.23	3.01	5.21	2.13	.16	.03	.28	.16	15.11
10 Year Average 1980-89	.45	.21	.54	.63	1.60	2.15	1.71	1.50	1.67	.76	.28	.34	11.84
11 Year Average 1980-90	.42	.19	.60	.63	1.65	2.23	2.03	1.55	1.53	.69	.29	.32	12.14
20 Year Average 1970-1989	.46	.45	.44	1.15	1.93	2.89	1.92	2.07	1.42	.69	.34	.43	14.19

* Westby data not available in 1985, 1986, and Jan-Jun of 1987, data from the station in nearby Plentywood was used for calculations.

daily water level fluctuations in an aquifer hydraulically connected to Medicine Lake indicate similar evaporation rates (Donovan,1988).

HYDROGEOLOGIC SETTING

Bedrock in the study area consists of interbedded sand, silt, clay, and lignite of the Paleocene Fort Union Formation. In this part of Sheridan County, bedrock is generally covered by younger sediments. Because of these intervening deposits, the interaction between lake water and ground water in the Fort Union Formation or deeper formations appears to be insignificant.

All of the lakes in this area are underlain by late-Wisconsinan glacial deposits. These deposits include outwash sand and gravel, lacustrine silt and clay, and till consisting of a mixture of sand, silt, clay, and boulders. Ground water in the glacial deposits is in direct connection with water in the lakes.

Post-glacial lake deposits typically overlie the glacial deposits within the lake basins. These consist of marls, tufas, evaporitic salts, clays, and organic debris. Very little information is currently available on the thickness and variability of these lake deposits. Current research by Joe Donovan (Penn State University) has focused on investigating the occurrence and origin of some of the Holocene lake deposits in Brush Lake and White Lake. These lake deposits form zones of water transfer between the water in the lakes and ground water in the surrounding sediments. The water chemistry of the individual lakes is dependent on geochemical reactions which include: dissolution of minerals exposed to lake water, precipitation of minerals from lake water, and similar reactions involving ground water moving in and out of the lakes. The concentrations of dissolved solids in these lakes depends chiefly on the flux of water moving out of an individual lake. As the flux of water through a lake is restricted, the concentration of dissolved solids is increased due to evaporation.

PURPOSE

Protection of the regions water resources was the primary driving force behind this investigation. The initial objective was to obtain representative water samples from a cross-section of lakes in this part of the state. Based on the water quality data, a lake classification scheme was developed. In addition, an attempt was made at determining what impacts, if any, have occurred to area lakes as a result of past land use practices.

Land uses that may have potentially impacted area water resources include agriculture related activities and oil field related activities. Farming could impact lakes if fertilizer, pesticides, and animal wastes are flushed into the lakes by runoff or ground water seepage. Expected impacts would include increased nutrients causing noxious organisms to flourish resulting in obnoxious odors, poisoning of wildlife, and shoreline degradation depending on the extent of contamination.

Oil-field activities that could impact lake water quality all relate to the extraction and production of hydrocarbons. Potential contaminants include additives used in the drilling process, saltwater in the drilling muds or produced along with the hydrocarbons, acid used in developing producing zones, and waste hydrocarbons. Previous ground water studies (Reiten, 1991, Payne and Reiten, 1991, and Reiten and Tischmak, in press) have determined produced brines as a major source of industrial contamination in the Montana portion of the Williston Basin. Impacts have included soil sterilization and aquifer water quality degradation. Several wells and stock ponds that previously had produced potable water have been degraded and are currently unusable. Environmentally unsound brine storage and disposal practices used during the 1960's and 1970's were the major causes of water quality degradation.

METHODS

Water samples were collected from about 50 lakes in eastern Sheridan County. A few water samples were also collected from borderline lakes in Williams and Divide Counties, North Dakota. Both named and unnamed lakes were sampled during this survey. Informal names were attached to the unnamed lakes to simplify interpretation and discussion. All of the lakes surveyed are identified on Plate 1. The location of the sampling sites are identified by Township, Range, Section, and Tract in the accompanying tables.

About 90 field water samples were collected and complete water analyses were run on 30 water samples. Twenty-nine of the analyses were conducted at the MBMG water lab in Butte and the remaining analysis was conducted at the water lab at Penn State University. Standard analytical procedures were used in analyzing all of the water samples.

All of the samples were tested for specific conductance and temperature at the sampling site. The conductivity meters used were calibrated using known standards to develop correction curves. Other parameters including dissolved oxygen, pH, and chloride concentration were measured for selected lake samples. Calibrated field instruments were used to measure dissolved oxygen and pH. Quantab chloride titrators were used to measure chloride concentration. At sample sites tested for only field parameters, water was collected by simply dipping an adequate volume from near the shoreline. At sample sites with complete lab analyses run, water was collected using the sampling system described below. A lake water sampling system was constructed using a tire inner tube mounted with a plywood platform in the center of the tube. Tygon tubing was inserted through the platform extending 15 to 25 centimeters below the platform. A screen was wrapped around the inlet portion of the tygon tubing to prevent clogging of the orifice. About 50-feet of tygon tubing was attached to the sampling platform enabling the water sample to be collected away from shore.

The sampling platform was thrown or floated out from shoreline and attached to a peristaltic pump for sample collection. This sampling system ensured collecting water from relatively similar depths in all lakes. Field parameters were measured immediately. Laboratory samples collected included raw unfiltered lake water and water filtered through 0.45 micron filters and preserved by refrigeration. Samples were acidified upon submittal to the MBMG lab in Butte. The Penn State sample was acidified following collection and also refrigerated.

RESULTS

The results of measurements of field water quality parameters are summarized in Table 2. The water samples were initially classified on the basis of field specific conductance (SC). The SC is a measure of the electrical conductivity of the water sample which is generally directly proportional to the dissolved solids concentration. Field values of SC were used to allow the comparison of a larger number of samples than if the comparison were restricted to samples analyzed in the lab. Five ranges of SC values were set up as categories for classifying the lakes. The five categories and associated SC ranges are listed below:

GROUP I 0 to 5000 umhos/cm

GROUP II 5000 to 10000 umhos/cm

GROUP III 10000 to 25000 umhos/cm

GROUP IV 25000 to 50000 umhos/cm

GROUP V more than 50000 umhos/cm

Plate 1 shows the distribution of these 5 lake water categories in the study area.

The range of field pH for all five water groups was from 8.60 to 10.00 based on samples collected for laboratory analysis (Figure 2). Water in Group I, III, IV, and V lakes displayed a wide range of pH values within each group. Water in Group II lakes had relatively uniform pH values ranging from 8.90 to 9.30. Field chloride concentrations in all lakes ranged from below detection limits to more than 9,300 mg/L.

TABLE 2. SHERIDAN COUNTY LAKES BASELINE FIELD WATER QUALITY
SAMPLED IN AUGUST/SEPTEMBER 1990

SITE ID	LAKE NAME	SAMPLE POINT	SAMPLE DATE	LOCATION	SPECIFIC CONDUCTANCE umhos/cm	pH	DISSOLVED OXYGEN (DO) MG/L	DO TEMP C	DO AS PERCENT OF SATURATION	FIELD CL MG/L	*CONTAMINATION INDEX	SAMPLE TYPE
091060	NODAK 1	A	08/23/90	15910308CDCC	98000	9.33	9.00	21.2	108	7276	0.074	LABGS
091065	NORTH TWIN	A	08/23/90	15910308DBDA	58450	9.61	7.60	29.0	101	3592	0.062	LABGS
091061	MIDDLE TWIN	A	08/23/90	15910308DDAB	36580	9.79	12.50	30.0	165	1016	0.028	LABGS
091064	SOUTH TWIN	B	08/23/90	15910309CCCA	39420							FIELD
091063	SOUTH TWIN	A	08/23/90	15910317AADD	41210	9.63	10.50	26.8	132	2266	0.055	LABGS
091062	VAN VOAST	A	08/23/90	15910317ABDB	79670	9.65	7.40	29.0	98		0.108	LABGS
091075	MILKY		08/26/90	16310334CBBB	5310	9.07				109	0.021	FIELD
091034	MEDICINE	D	08/29/90	31N56E05CDBC	4420							FIELD
091033	MEDICINE	C	08/29/90	31N56E06BBAD	4180							FIELD
091027	MEDICINE	E	08/29/90	31N56E09BBDD	4580	9.22	8.60	22.0	97	74	0.016	LAB
091035	MEDICINE	F	08/29/90	31N56E13CCDC	4760							FIELD
091037	GAFFNEY	H	08/29/90	31N57E04CCBB	4870							FIELD
091036	MEDICINE	G	08/29/90	31N57E05DDDB	4320							FIELD
091032	MEDICINE	B	08/29/90	32N56E31CCBB	650							FIELD
091031	MEDICINE	A	08/29/90	32N56E33CBBB	4690							FIELD
091039	NO. 12	A	08/22/90	32N57E13CDAA	5100							FIELD
091003	NO. 12	B	08/24/90	32N57E13DBDB	6300	8.94	9.40	24.0	110	59	0.009	LAB
091030	NO. 12	B	08/22/90	32N57E13DBDB	4210							FIELD
091038	MEDICINE	J	08/29/90	32N57E31CAAD	4670							FIELD

Table 2 (continued)

SITE ID	LAKE NAME	SAMPLE POINT	SAMPLE DATE	LOCATION	SPECIFIC CONDUCTANCE umhos/cm	pH	DISSOLVED OXYGEN (DO) MG/L	DO TEMP C	DO AS PERCENT OF SATURATION	FIELD CL MG/L	*CONTAMINATION INDEX	SAMPLE TYPE
091026	DEEP	I	08/29/90	32N57E32BBAB	5340	9.30	7.70	22.1	87	128	0.024	LAB
091049	LONG	C	08/22/90	32N58E02CCCC	5440							FIELD
091047	LONG	A	08/22/90	32N58E03AACB	5360							FIELD
091006	LONG	D	08/25/90	32N58E03ACAD	5200	9.12	9.40	22.0		84	0.016	LAB
091048	LONG	B	08/22/90	32N58E03DACC	5370							FIELD
091044	NO. 12	G	08/22/90	32N58E04CDCD	4750							FIELD
091051	FRED	B	08/22/90	32N58E04DAAA	2260							FIELD
091008	FRED	A	08/24/90	32N58E04DAAD	2230	9.92	11.10	25.0	126		0.005	LAB
091090	FRED	A	08/22/90	32N58E04DAAD	2300							FIELD
091052	FRED	C	08/22/90	32N58E04DABA	2190							FIELD
091053	FRED	D	08/22/90	32N58E04DACB	2280							FIELD
091043	NO. 12	F	08/22/90	32N58E08DCCC	5610							FIELD
091005	BERGER POND	B	08/24/90	32N58E09AAAB	22990	10.01	11.00	25.5	134	823	0.036	LAB
091045	NO. 12	H	08/22/90	32N58E09BABA	5910							FIELD
091046	BERGER POND	A	08/22/90	32N58E10BBBD	24440							FIELD
091004	KATY	A	08/24/90	32N58E17CDDB	31190	9.72	5.50	27.0	68	745	0.024	LAB
091088	KATY	A	08/22/90	32N58E17CDDB	20000							FIELD
091042	NO. 12	E	08/22/90	32N58E18AADB	6300							FIELD
091041	NO. 12	D	08/22/90	32N58E18ACAB	5545							FIELD
091040	NO. 12	C	08/22/90	32N58E18ACCB	5190							FIELD

Table 2 (continued)

SITE ID	LAKE NAME	SAMPLE POINT	SAMPLE DATE	LOCATION	SPECIFIC CONDUCTANCE umhos/cm	pH	DISSOLVED OXYGEN (DO) MG/L	DO TEMP C	DO AS PERCENT OF SATURATION	FIELD CL MG/L	*CONTAMINATION INDEX	SAMPLE TYPE
091067	CLEAR	C	08/23/90	33N58E03ADAA	12020							FIELD
091001	CLEAR	B	08/23/90	33N58E05AABC	11900	9.36	9.60	24.0	113	128	0.011	LAB
091012	BEER BOTTLE		08/26/90	33N58E22ABAB	15890	9.09	7.10	16.3	72		0.017	LAB
091094	BRUSH		08/09/90	33N58E22DBDA01	6144	9.20	9.00	22.2	102		0.012	LABGS
091021	HORSESHOE	A	08/30/90	33N58E24DDDA	83400	9.96	4.00	26.0	53		0.092	LAB
091093	HORSESHOE	A	08/23/90	33N58E24DDDA	72750							FIELD
091029	EAST WHITE		08/31/90	33N58E26BADD	14500	9.04	11.00	18.0	116		0.018	LAB
091002	HORSEFLY	A	08/24/90	33N58E27AABB	27800	9.23	6.90	22.0	78		0.013	LAB
091028	WEST WHITE		09/03/90	33N58E27ACBC	16420	9.24	11.00	20.0	126		0.016	LAB
091058	BETTY	C	08/22/90	33N58E27CBAA	9660							FIELD
091007	BETTY	A	08/24/90	33N58E27CBCC	9350	9.24	5.50	24.2	65	101	0.011	LAB
091089	BETTY	A	08/22/90	33N58E27CBCC	9670							FIELD
091057	BETTY	B	08/22/90	33N58E27CBDB	8990							FIELD
091059	TERESA	B	08/22/90	33N58E28CDBA	15990							FIELD
091009	TERESA	A	08/24/90	33N58E28DCBC	15120	9.72	12.60	24.0	148		0.009	LAB
091091	TERESA	A	08/22/90	33N58E28DCBC	16190							FIELD
091011	JOHN	A	08/25/90	33N58E29DACC	3070	9.03	7.00	25.0	84		0.009	LAB
091056	JOHN	B	08/25/90	33N58E29DCDD	3260							FIELD
091010	MALLARD POND	C	08/25/90	33N58E33BCBC	2590	9.48	9.12	22.0	103		0.010	LAB
091054	MALLARD POND	A	08/22/90	33N58E33BCDA	1475							FIELD

Table 2 (continued)

SITE ID	LAKE NAME	SAMPLE POINT	SAMPLE DATE	LOCATION	SPECIFIC CONDUCTANCE umhos/cm	pH	DISSOLVED OXYGEN (DO) MG/L	DO TEMP C	DO AS PERCENT OF SATURATION	FIELD CL MG/L	*CONTAMINATION INDEX	SAMPLE TYPE
091055	MALLARD POND	B	08/25/90	33N58E33BCDC	2610							FIELD
091050	BLACKWATER	A	08/25/90	33N58E35CCAD	88700							FIELD
091066	CLEAR	A	08/23/90	34N58E33BCCB	8690							FIELD
091071	S. GOOSE	F		35N58E01BAAA	69345					3290	0.047	FIELD
091069	S. GOOSE	A	08/26/90	35N58E11DAAD	21000					668	0.032	FIELD
091016	S. GOOSE	B	08/27/90	35N58E12DADA	28790	9.42	8.40	19.8	92	900	0.031	LAB
091092	S. GOOSE	B	08/26/90	35N58E12DADA	28740	9.42	8.40	19.8	92	900	0.031	FIELD
091013	BEEHIVE	A	08/26/90	35N58E13AADC	11150	9.09	6.40	18.5	68	246	0.022	LAB
091068	ISLAND	A	08/26/90	35N58E36AAAA	3590							FIELD
091024	MUDCRACK		08/29/90	36N57E34BCBA	27690	9.38	8.60	21.8	102	4740	0.171	LAB
091018	GAULKE	A	08/26/90	36N58E01DAAD	7170	9.15	10.20	19.3	110	59	0.008	LAB
091074	GAULKE	B	08/26/90	36N58E01DDAC	7210							FIELD
091076	ROUND	A	08/26/90	36N58E01DDDD	28390	9.52				1210	0.043	FIELD
091087	MCELROY		08/28/90	36N58E09DDBA	358							FIELD
091078	NORTH		08/27/90	36N58E12CAAD	8540	9.16				308	0.036	FIELD
091077	ROUND	B	08/26/90	36N58E12DBCA	38790	9.59				1521	0.039	FIELD
091015	FOOTBALL		08/26/90	36N58E13AADD	25860	9.65	20.00	20.0	224	2621	0.101	LAB
091073	NE WESTBY		08/26/90	36N58E13AADD	30120	9.72				3638	0.121	FIELD
091017	S. WESTBY		08/27/90	36N58E24DADD	89900	9.88	10.00	27.0	127	2071	0.023	LAB
091014	N. GOOSE	C	08/26/90	36N58E25DADC	70800	9.31	10.00	21.0	115	3638	0.051	LAB

Table 2 (continued)

SITE ID	LAKE NAME	SAMPLE POINT	SAMPLE DATE	LOCATION	SPECIFIC CONDUCTANCE umhos/cm	pH	DISSOLVED OXYGEN (DO) MG/L	DO TEMP C	DO AS PERCENT OF SATURATION	FIELD CL MG/L	*CONTAMINATION INDEX	SAMPLE TYPE
091025	NW GOOSE		08/29/90	36N58E26CBAD	83300	9.61	4.30	23.2	55	9394	0.113	LAB
091072	N. GOOSE (GW)	E	08/27/90	36N58E36CDCC	18960					595	0.031	FIELD
091070	N. GOOSE	D	08/27/90	36N58E36CDDC	70940	9.31				3290	0.046	FIELD
091022	SALT		08/28/90	37N56E01BCAC	59560	9.25	7.70	24.3	92	1521	0.026	LAB
091085	NO FREEZE		08/28/90	37N57E01DCAC	81270					2516	0.031	FIELD
091084	N.WIDGEON SLGH		08/28/90	37N57E07DADC	1510							FIELD
091019	LARSON SLOUGH		08/27/90	37N57E15DCBC	1150	8.68	10.50	22.5	120	52	0.045	LAB
091023	LONE TREE		08/28/90	37N57E20DCAC	31680	8.96	11.60	23.8	137	1521	0.048	LAB
091083	WEED POND		08/27/90	37N58E07DCCD	8130	8.42				1055	0.130	FIELD
091082	MIRROR		08/27/90	37N58E18AADC	42310	9.11				2621	0.062	FIELD
091086	CHEVRON		08/28/90	37N58E18CCBB	7230					1751	0.242	FIELD
091081	SCUM		08/27/90	37N58E20ADDC	42890	9.58				3638	0.085	FIELD
091020	RUSTY		08/28/90	37N58E30CCBB	27910	9.16	9.00	23.2	105	745	0.027	LAB
091080	FLAT		08/27/90	37N58E33ADCC	7380	9.16				600	0.081	FIELD
091079	CURVE		08/27/90	37N58E34CCDD	5820	9.06				542	0.093	FIELD

* The contamination index refers to the ratio of chloride concentration to field SC. Field chloride concentrations are used in this ratio when available; when unavailable lab chloride concentrations are used.

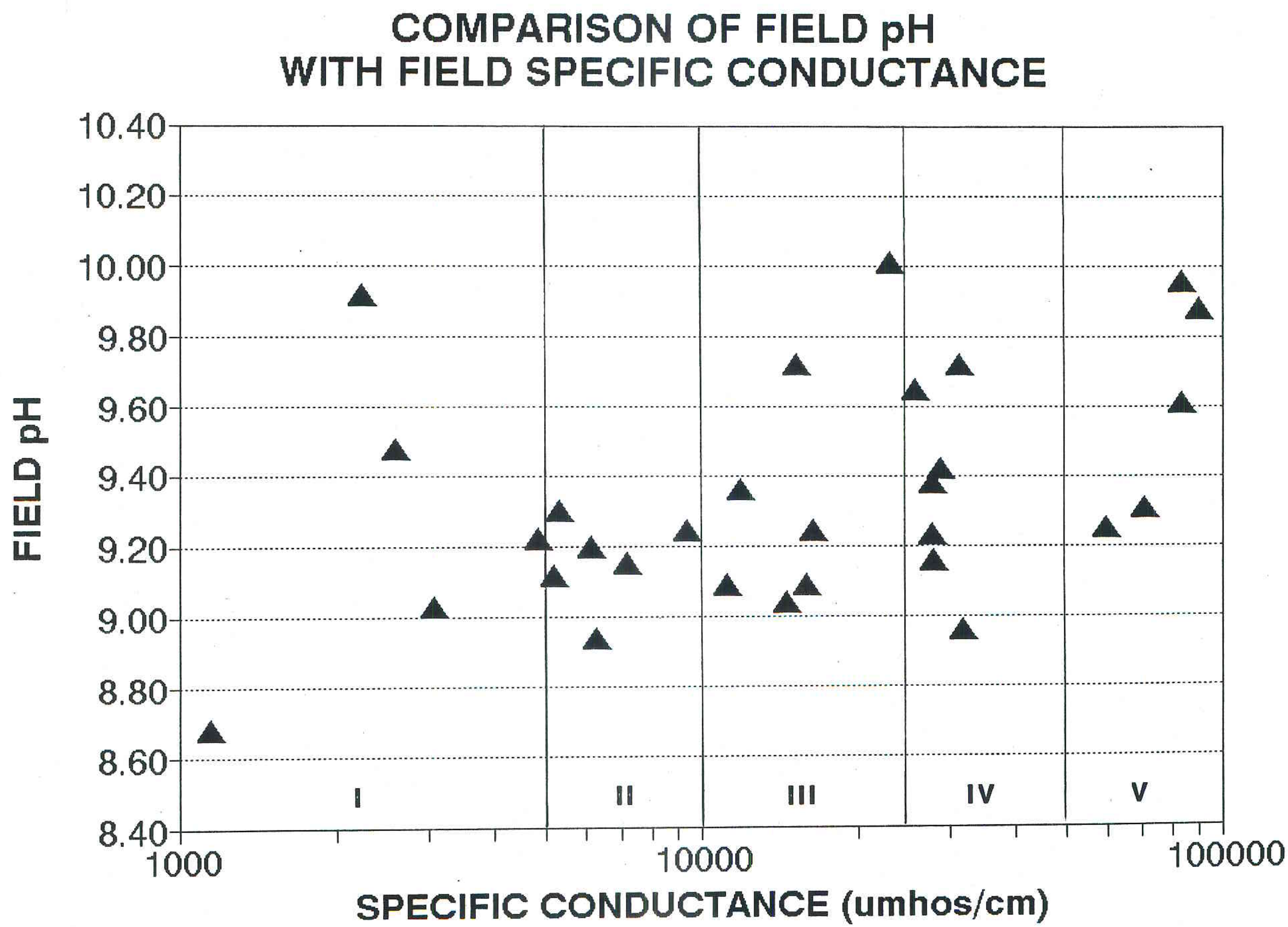

Figure 2. Comparison of the field pH values with $\log_{10}$ SC in water from selected Sheridan County lakes. Grouping of lakes based on SC are depicted by Roman numerals I through V.

The results of the laboratory analyses of the lake water samples are summarized in Table 3. A comparison of the relationship between $\log_{10}$ SC and $\log_{10}$ calculated dissolved solids is relatively linear for lake water in Groups I and II. This relationship is shown in Figure 3. At these concentrations (0 - 10,000 umhos/cm) the field SC tends to be consistently higher than dissolved solids. The relationship changes to a nearly 1:1 ratio of field SC to dissolved solids for Groups III and IV (10,000 - 50,000 umhos/cm). The relationship breaks down for high salinity Group V waters (>50,000 umhos/cm) and field SC is significantly lower than dissolved solids.

LAKE WATER QUALITY

The five different categories of lakes based on SC makes a good starting point for a more detailed look at the types of dissolved constituents found in the lake water. Plots of major cations and anions can also be developed to produce graphical images that aid in identifying the dominant ions in a particular water sample. One such type of plot is the semi-logarithmic Schoellor diagram (Freeze and Cherry, 1979). Figure 4 depicts five Schoellor plots indicating the mean concentrations of major cations and anions by Group in the lakes sampled.

The shape of the curves maps the relative proportions of the dominant cations and anions within each category of lake water. In general, the shape of the curves are very similar for all 5 groups. The upward shift from Group I to Group V corresponds to the overall increase in dissolved minerals.

The concentration of a particular ion can be evaluated by noting the position it plots on the Y-axis of the Schoellor plot.

TABLE 3. WATER QUALITY OF SELECTED LAKES, SHERIDAN COUNTY, MONTANA
(negative values are below detection limits)

LAKE NAME	LOCATION	SITE ID	DATE SAMPLED	LAB NUMBER	CALCIUM (mg/L)	MAGNESIUM (mg/L)	SODIUM (mg/L)	POTASSIUM (mg/L)	IRON (mg/L)	MANGANESE (mg/L)	SILICA (mg/L)	BICAR-BONATE (mg/L)	CARBON-ATE (mg/L)	CHLORIDE (mg/L)	SULFATE (mg/L)	NITRATE (mg/L)	FLOU-RIDE (mg/L)
MEDICINE	31N56E09BBDD01	91027	08/29/90	90Q0326	16.60	141.00	1050.0	49.7	0.144	0.012	3.85	1240.0	192.0	71.3	1460.0	0.32	0.3
NUMBER 12	32N57E13DBDB01	91003	08/24/90	90Q0346	18.80	517.00	1030.0	96.6	0.024	-0.002	16.20	1200.0	134.0	61.2	3080.0	1.08	0.1
DEEP LAKE	32N57E32BBAB01	91026	08/29/90	90Q0337	16.60	89.30	1280.0	59.6	0.197	0.020	5.64	1464.0	197.0	96.8	1500.0	0.17	0.2
SOUTH LONG	32N58E03ACAD01	91006	08/25/90	90Q0324	9.52	161.00	1190.0	88.7	0.131	0.011	12.20	1870.0	254.0	90.6	1270.0	0.25	0.2
FRED	32N58E04DAAD01	91008	08/24/90	90Q0347	6.16	151.00	430.0	23.1	0.013	-0.002	15.20	700.0	305.0	11.6	515.0	0.07	0.1
BERGER POND	32N58E09AAAB01	91005	08/24/90	90Q0338	3.05	139.00	9740.0	350.0	-0.004	-0.002	7.00	9690.0	4030.0	977.0	7060.0	-0.10	1.1
KATY	32N58E17CDDB01	91004	08/24/90	90Q0336	1.92	111.00	11240.0	554.0	0.027	0.008	1.33	7420.0	3310.0	725.0	12800.0	-0.10	0.2
CLEAR	33N58E05AABC01	91001	08/23/90	90Q0323	4.00	322.00	2990.0	272.0	0.037	0.006	5.48	2420.0	624.0	128.0	4760.0	-0.07	0.0
BEER BOTTLE	33N58E22ABAB01	91012	08/26/90	90Q0335	8.12	706.00	3780.0	246.0	0.122	0.012	2.38	1810.0	304.0	265.0	8640.0	-0.07	0.0
HORSEFLY	33N58E27AABB01	91002	08/24/90	90Q0331	3.03	411.00	7360.0	360.0	0.049	0.002	-0.10	3760.0	880.0	365.0	1280.0	0.10	0.1
BETTY	33N58E27CBCC01	91007	08/24/90	90Q0334	3.93	335.00	2220.0	194.0	0.028	0.013	2.52	2920.0	648.0	75.1	2860.0	-0.07	0.1
TERESA	33N58E28DCBC01	91009	08/24/90	90Q0340	2.88	194.00	4110.0	320.0	-0.004	0.007	4.42	3580.0	1420.0	135.0	4650.0	-0.07	0.1
JOHN	33N58E29DACC01	91011	08/25/90	90Q0342	12.40	191.00	610.0	89.5	0.076	0.009	6.84	1200.0	137.0	27.7	947.0	1.19	0.1
MALLARD POND	33N58E33BCBD01	91010	08/25/90	90Q0325	12.30	131.00	471.0	33.5	0.016	0.007	13.00	632.0	122.0	25.7	864.0	-0.07	0.4
BRUSH	33N59E22DBDA01	91094	08/09/90	90P0107	5.00	270.90	1379.0	93.6	0.040	0.015	6.40	1599.0	94.0	76.1	2415.0	0.06	2.8
HORSESHOE	33N59E24DDDA01	91021	08/30/90	90Q0365	1.63	29.00	108000.0	750.0	0.797	0.012	22.00	71000.0	54800.0	7690.0	75700.0	-0.20	10.5
EAST WHITE	33N59E26BADD01	91029	08/31/90	90Q0367	24.60	944.00	3410.0	369.0	0.038	-0.002	0.00	1601.0	240.0	258.0	9310.0	0.82	0.1
WEST WHITE	33N59E27ACAB01	91028	09/03/90	90Q0366	6.26	621.00	4660.0	358.0	0.178	0.010	12.50	3790.0	496.0	262.0	8720.0	0.38	0.3
S. GOOSE	35N58E12DADA01	91016	08/27/90	90Q0327	8.83	274.00	8840.0	224.0	0.118	0.060	3.27	2740.0	816.0	1070.0	14800.0	-0.07	0.4
BEEHIVE	35N58E13AADC01	91013	08/26/90	90Q0344	10.20	272.00	3100.0	181.0	0.096	0.018	3.36	2650.0	388.0	256.0	4790.0	1.47	0.2
GAULKE	36N58E01DAAD01	91018	08/26/90	90Q0328	13.60	118.00	1800.0	35.3	0.073	0.005	3.19	1120.0	173.0	79.5	3040.0	-0.07	0.1
FOOTBALL	36N58E13AADD01	91015	08/26/90	90Q0333	24.60	302.00	7170.0	130.0	0.180	0.012	6.89	979.0	372.0	3070.0	11000.0	0.10	0.1
S. WESTBY	36N58E24DADD01	91017	08/27/90	90Q0343	4.04	30.90	56000.0	520.0	0.126	0.008	15.00	15900.0	10400.0	2870.0	84600.0	-0.20	1.4
N. GOOSE	36N58E25DADC01	91014	08/26/90	90Q0330	7.13	512.00	32700.0	1050.0	0.036	0.003	-0.10	9300.0	3670.0	4110.0	53000.0	-0.10	0.0
NW GOOSE	36N58E26CBAD01	91025	08/26/90	90Q0345	376.00	1600.00	47000.0	704.0	0.046	0.015	0.30	309.0	108.0	10500.0	93300.0	-0.20	0.0
MUD CRACK	36N58E34BCBA01	91024	08/29/90	90Q0332	299.00	1940.00	5780.0	322.0	0.310	0.016	1.98	212.0	47.2	4180.0	15100.0	-0.10	0.0
SALT	37N56E01BCAC01	91022	08/28/90	90Q0348	346.00	3000.00	24400.0	459.0	0.893	0.033	8.41	502.0	81.6	1530.0	61200.0	-0.10	0.0
LARSON SLOUGH	37N57E15DCBC01	91019	08/27/90	90Q0339	94.60	59.70	219.0	35.0	0.091	0.053	24.20	349.0	28.8	49.6	591.0	-0.07	0.2
LONE TREE	37N57E20DCAC01	91023	08/28/90	90Q0329	27.70	2270.00	8740.0	714.0	0.092	0.010	4.31	2290.0	216.0	2120.0	23300.0	0.20	0.0
RUSTY	37N58E30CCBB01	91020	08/28/90	90Q0341	19.50	1280.00	7950.0	163.0	0.060	0.011	8.35	1880.0	461.0	865.0	18700.0	-0.10	0.1

TABLE 3. WATER QUALITY OF SELECTED LAKES, SHERIDAN COUNTY, MONTANA (continued)
(negative values are below detection limits)

LAKE NAME	LAB NUMBER	CALCULATED DISSOLVED SOLIDS (mg/L)	SUM OF DISSOLVED SOLIDS (mg/L)	FIELD CONDUCTIVITY (mg/L)	FIELD TEMPERATURE	LAB CONDUCTIVITY (mg/L)	FIELD pH	LAB pH	SODIUM ADSORPTION RATE	VANADIUM (mg/L)	ZINC (mg/L)	ZIRCONIUM (mg/L)	ORTHO-PHOSPHATE (mg/L)
MEDICINE	90Q0326	3596	4225	4850	21.4	4727.0	9.22	9.49	18.32	0.017	-0.006	-0.006	
NUMBER 12	90Q0346	5546	6155	6300	25.3	6525.0	8.94	8.87	9.61	0.013	-0.006	-0.006	
DEEP LAKE	90Q0337	3967	4710	5340	21.5	5520.0	9.30	9.35	27.54	0.006	-0.006	-0.006	
SOUTH LONG	90Q0324	3998	4947	5200	22.0	5396.0	9.12	9.41	19.76	0.015	-0.006	-0.006	0.00
FRED	90Q0347	1802	2157	2230	25.0	2282.0	9.92	10.02	7.41	-0.004	-0.006	-0.006	
BERGER POND	90Q0338	27080	31997	22990	25.5	27769.0	10.01	9.74	176.03	-0.004	-0.006	-0.006	
KATY	90Q0336	32399	36163	31190	26.5	32748.0	9.72	9.78	227.64	-0.004	-0.006	0.007	
CLEAR	90Q0323	10297	11525	11900	23.3	11374.0	9.36	9.74	35.61	0.012	-0.006	0.006	0.00
BEER BOTTLE	90Q0335	14843	15762	15890	16.7	15949.0	9.09	9.05	30.41	0.009	-0.006	0.007	
HORSEFLY	90Q0331	24031	25939	27800	19.0	24490.0	9.23	9.29	77.70	0.005	-0.006	0.013	
BETTY	90Q0334	7777	9259	9350	21.0	9350.0	9.24	9.34	25.92	0.008	-0.006	0.009	
TERESA	90Q0340	12600	14416	15120	24.7	74957.0	9.72	9.79	63.01	-0.004	-0.006	-0.006	
JOHN	90Q0342	2614	3223	3070	25.2	3572.0	9.03	9.07	9.29	-0.004	-0.006	-0.006	
MALLARD POND	90Q0325	1984	2305	2590	21.9	2684.0	9.48	9.52	8.59	0.015	-0.006	-0.006	0.00
BRUSH	90P0107	5131	5944	6144	22.2	5070.0	9.20	9.11	17.87		0.000	0.000	0.00
HORSESHOE	90Q0365	282001	318026	83400	25.8	98083.0	9.96	10.01	4230.14	-0.004	0.117	-0.114	22.50
EAST WHITE	90Q0367	15345	16157	14500	18.6	14846.0	9.04	8.94	23.62	0.004	-0.006	-0.006	
WEST WHITE	90Q0366	17003	18926	16420	20.4	17952.0	9.24	9.23	39.99	-0.004	-0.006	-0.006	-0.10
S. GOOSE	90Q0327	27386	28777	28790	19.9	27374.0	9.42	9.79	113.44	0.008	-0.006	-0.006	
BEEHIVE	90Q0344	10308	11652	11150	18.4	12579.0	9.09	9.11	39.87	-0.004	-0.006	0.007	
GAULKE	90Q0328	5815	6383	7170	19.6	7291.0	9.15	9.43	34.36	0.008	-0.006	-0.006	
FOOTBALL	90Q0333	22558	23055	25860	20.0	17952.0	9.65	9.60	86.39	0.005	-0.006	-0.006	
S. WESTBY	90Q0343	162274	170341	89900	23.0	60143.0	9.88	9.95	2079.91	-0.004	-0.006	-0.006	
N. GOOSE	90Q0330	99630	104349	70800	20.8	57987.0	9.31	9.38	308.67	-0.004	-0.006	-0.006	
NW GOOSE	90Q0345	153741	153897	83300	22.5	61732.0	9.61	9.00	235.78	0.009	-0.006	-0.006	
MUD CRACK	90Q0332	27775	27882	27690	22.4	28872.0	9.38	8.72	26.92	0.011	-0.006	-0.006	
SALT	90Q0348	91273	91528	59560	23.2	50185.0	9.25	8.86	92.38	-0.004	-0.006	-0.006	
LARSON SLOUGH	90Q0339	1274	1451	1150	22.5	1746.0	8.68	8.89	4.34	-0.005	-0.006	-0.006	
LONE TREE	90Q0329	38520	39682	31680	24.8	33661.0	8.96	9.41	39.20	-0.004	-0.006	-0.006	
RUSTY	90Q0341	30373	31327	27910	22.9	28791.0	9.16	9.06	47.44	-0.004	-0.006	-0.006	

TABLE 3. WATER QUALITY OF SELECTED LAKES, SHERIDAN COUNTY, MONTANA (continued)
(negative values are below detection limits)

LAKE NAME	LAB NUMBER	ALUMINUM (mg/L)	SILVER (mg/L)	ARSENIC (mg/L)	BORON (mg/L)	CADIMUM (mg/L)	CHROMIUM (mg/L)	COPPER (mg/L)	LITHIUM (mg/L)	MOLYBDENUM (mg/L)	BARIUM (mg/L)	BROMIDE (mg/L)	NICKEL (mg/L)	LEAD (mg/L)	SELENIUM (mg/L)	STRONTIUM (mg/L)	TITANIUM (mg/L)
MEDICINE	90Q0326	0.05	-0.004	0.035	2.12	-0.005	-0.005	0.017	0.149	-0.04	0.05	0.60	-0.02	-0.05	-0.001	0.44	-0.004
NUMBER 12	90Q0346	-0.04	-0.004	0.050	1.47	-0.005	-0.005	-0.004	0.580	-0.04	0.03	0.29	0.02	0.05	-0.001	0.35	-0.004
DEEP LAKE	90Q0337	0.08	-0.004	0.046	0.65	-0.005	-0.005	0.013	0.140	-0.04	0.04	1.70	-0.02	-0.05	-0.008	0.37	-0.004
SOUTH LONG	90Q0324	0.13	-0.004	0.022	1.56	-0.005	0.006	0.009	0.370	-0.04	0.02	1.60	-0.02	-0.05	0.007	0.16	-0.004
FRED	90Q0347	0.04	-0.004	0.004	0.79	-0.005	-0.005	-0.004	0.175	-0.04	0.01	-0.10	-0.02	-0.05	-0.001	0.02	-0.004
BERGER POND	90Q0338	-0.04	-0.004	0.045	7.96	-0.005	-0.005	0.004	1.260	-0.04	-0.01	16.30	-0.02	-0.05	-0.001	0.03	-0.004
KATY	90Q0336	-0.04	-0.004	0.164	6.43	-0.005	-0.005	0.017	1.700	-0.04	0.01	19.70	-0.02	-0.05	0.001	0.08	-0.004
CLEAR	90Q0323	0.06	-0.004	0.034	4.59	-0.005	0.007	-0.004	1.380	-0.04	-0.01	1.70	-0.02	-0.05	-0.001	0.01	-0.004
BEER BOTTLE	90Q0335	0.08	-0.004	0.065	6.49	0.006	-0.005	-0.004	2.110	-0.04	0.01	2.90	0.02	0.13	-0.001	0.16	-0.004
HORSEFLY	90Q0331	-0.04	-0.004	0.015	9.99	-0.005	-0.005	-0.004	2.370	-0.04	0.01	6.60	-0.02	0.08	-0.001	0.14	-0.004
BETTY	90Q0334	-0.04	-0.004	0.033	5.65	-0.005	-0.005	0.005	0.940	-0.04	0.01	1.10	-0.02	-0.05	-0.001	0.01	-0.004
TERESA	90Q0340	-0.04	-0.004	0.044	7.57	-0.005	-0.005	0.024	1.120	-0.04	0.01	1.15	-0.02	0.05	-0.001	0.03	-0.004
JOHN	90Q0342	-0.04	0.042	0.023	1.35	-0.005	-0.005	-0.004	0.346	-0.04	0.03	-0.10	-0.02	-0.05	-0.001	0.18	-0.004
MALLARD POND	90Q0325	0.04	-0.004	0.011	0.65	-0.005	-0.005	-0.004	0.201	-0.04	0.01	-0.10	-0.02	-0.05	0.008	0.08	-0.004
BRUSH	90P0107	0.00	0.000	0.000	0.00	0.000	0.000	0.000	0.200	0.00	0.00	1.23	0.00	0.00	0.000	0.20	0.000
HORSESHOE	90Q0365	-0.04	-0.004	2.000	20.30	-0.005	-0.005	-0.004	1.280	0.07	0.08	170.00	-0.02	-0.05	0.001	0.20	0.052
EAST WHITE	90Q0367	0.04	-0.004	0.121	7.89	0.011	-0.005	0.006	2.180	-0.04	0.03	4.30	-0.02	0.13	-0.001	0.21	-0.004
WEST WHITE	90Q0366	-0.04	-0.004	0.073	8.83	0.006	-0.005	0.005	2.070	-0.04	0.02	3.60	0.05	0.05	-0.001	0.15	-0.004
S. GOOSE	90Q0327	-0.04	-0.004	0.043	5.70	-0.005	-0.005	0.029	1.210	-0.04	0.01	2.90	-0.02	0.06	-0.001	0.03	-0.004
BEEHIVE	90Q0344	0.09	-0.004	0.023	2.87	0.005	0.006	0.036	0.720	-0.04	0.02	0.70	-0.02	0.05	-0.001	0.04	-0.004
GAULKE	90Q0328	0.05	-0.004	0.013	1.56	-0.005	-0.005	-0.004	0.425	-0.04	0.01	1.10	-0.02	-0.05	0.006	0.18	-0.004
FOOTBALL	90Q0333	0.05	-0.004	0.021	6.80	-0.005	-0.005	-0.004	0.635	-0.04	0.02	52.60	-0.02	0.08	-0.001	0.34	-0.004
S. WESTBY	90Q0343	-0.04	0.040	0.225	11.70	-0.005	-0.005	0.106	1.250	-0.04	-0.01	46.00	-0.02	-0.05	0.001	0.04	-0.004
N. GOOSE	90Q0330	-0.04	-0.004	0.147	19.30	-0.005	-0.005	-0.004	5.190	-0.04	0.01	48.70	-0.02	-0.05	-0.001	-0.06	-0.004
NW GOOSE	90Q0345	0.07	0.067	0.020	14.30	0.007	-0.005	0.050	8.320	-0.04	0.04	35.10	-0.02	-0.05	0.001	6.31	0.016
MUD CRACK	90Q0332	0.29	0.080	0.017	7.37	0.010	-0.005	0.032	1.650	0.20	0.05	6.08	0.05	0.36	0.002	4.70	0.017
SALT	90Q0348	0.67	0.032	0.039	13.30	0.026	-0.005	0.024	3.190	-0.04	0.02	13.40	0.07	0.34	0.002	7.89	0.025
LARSON SLOUGH	90Q0339	0.22	0.026	0.014	0.05	-0.005	-0.005	-0.004	0.050	-0.04	0.05	0.10	-0.02	-0.05	-0.001	0.40	-0.005
LONE TREE	90Q0329	0.08	-0.004	0.088	2.74	0.015	-0.005	0.115	3.360	-0.04	0.03	18.00	0.05	0.33	-0.009	1.26	-0.004
RUSTY	90Q0341	0.04	-0.004	0.164	6.01	-0.005	-0.005	-0.004	1.500	-0.04	0.02	8.90	-0.02	0.18	0.001	0.14	-0.004

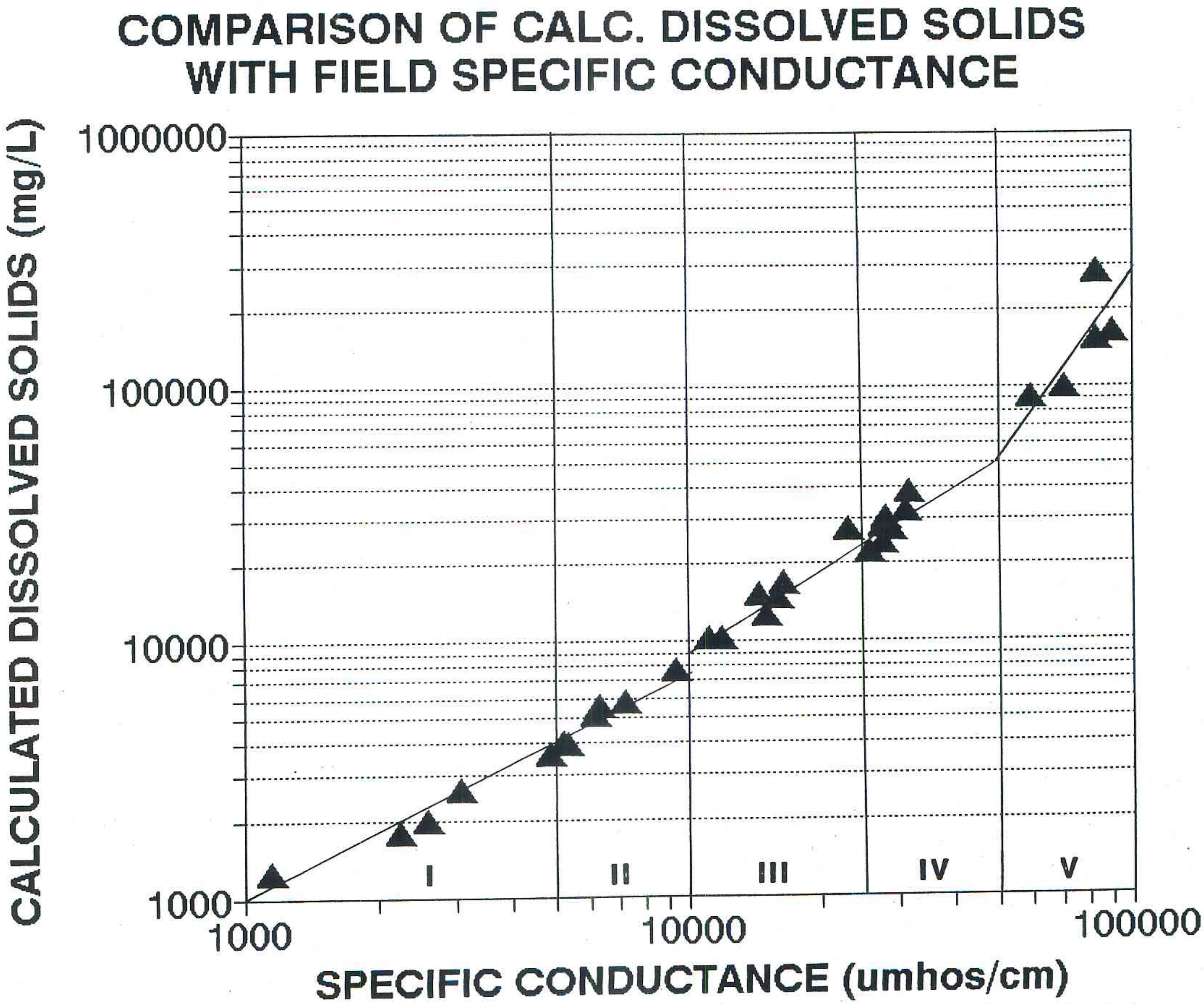

Figure 3. Comparison of the log calculated dissolved solids with $\log_{10}$ SC in water from selected Sheridan County lakes showing the change in this relationship as lake water becomes more mineralized. Grouping of lakes based on SC are depicted by Roman numerals I through V.

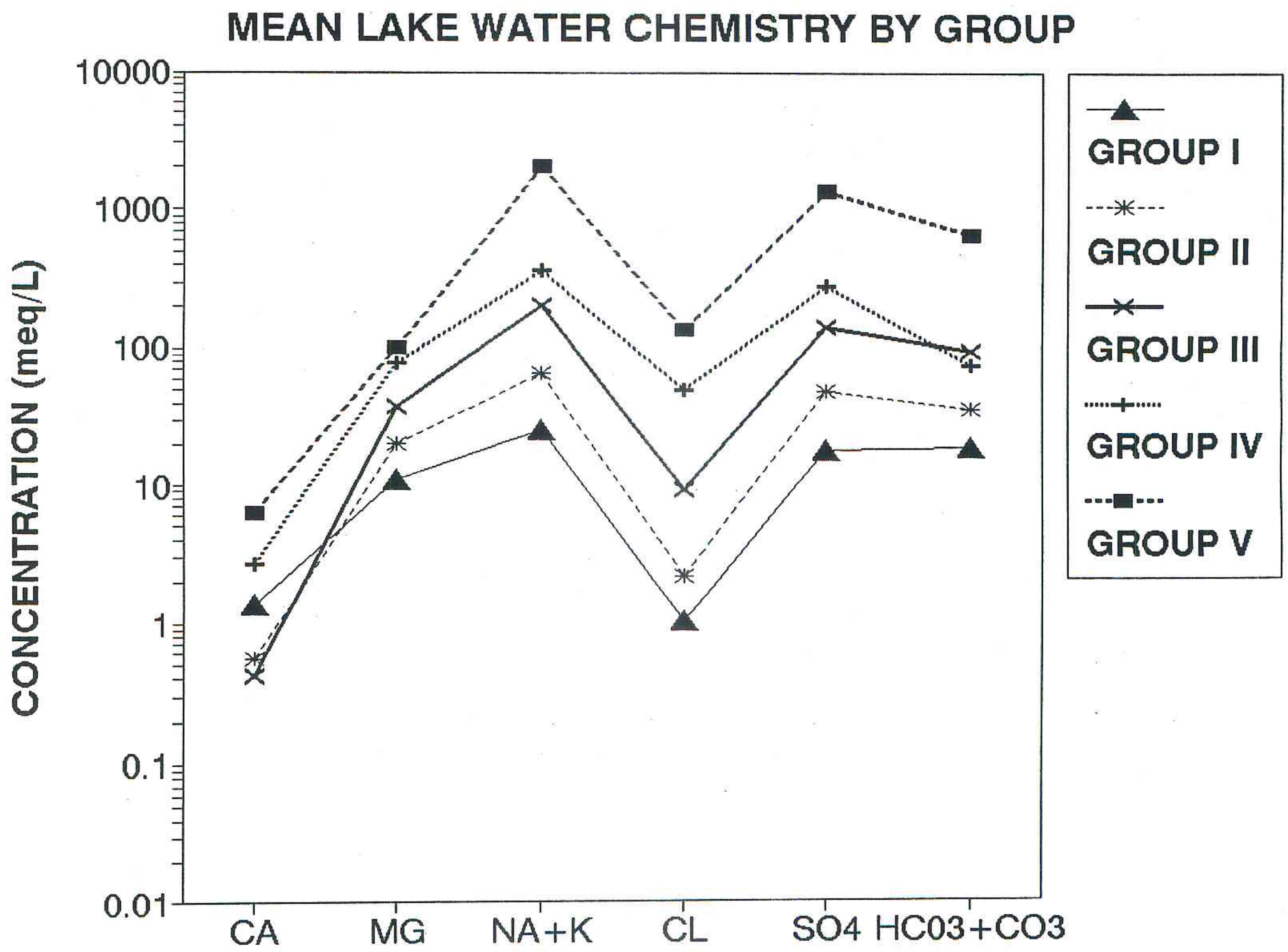

Figure 4. Semilogarithmic plots indicating the mean concentrations of major cations and anions by Group in the lakes sampled.

The relationship between different ions can be compared by observing the slope of a line connecting the mean concentrations for each ion. Sodium and sulfate are the dominant cation and anion in each of the five different water groups. Bicarbonate plus carbonate ions are proportionally only slightly less concentrated than sulfate ions in Group I, Group II, and Group III lake waters, but are in relatively low concentrations in Group IV and Group V lake waters. The concentrations of magnesium are intermediate and in similar proportions in all five water groups. Calcium and chloride ions are all in relatively low concentrations in all five water groups. The ranking of cation concentrations is NA > MG > CA and for anion concentrations is SO4 > HCO3 + CO3 > CL for all five water groups.

A series of plots showing the relationship of the $\log_{10}$ concentrations of the major cations and anions with the $\log_{10}$ SC are displayed in Figures 5 and 6. With SC plotted along the x-axis the distribution of the ionic concentration by the associated lake Group is apparent.

Calcium concentrations vary most in both the freshest (Group I) and most mineralized (Group IV and V) lakes (Figure 5a). A best fit line projected through Group I, Group II, and Group III data points indicate a decreasing trend in dissolved calcium up to an SC of 25,000 umhos/cm. The trend breaks down in highly concentrated water of Group IV and V lakes. This trend probably relates to the deposition of marl on the lake bottoms as the waters become supersaturated with calcium and bicarbonate ions.

The variability of magnesium concentrations in lake water increases as the water becomes more mineralized (Figure 5b).

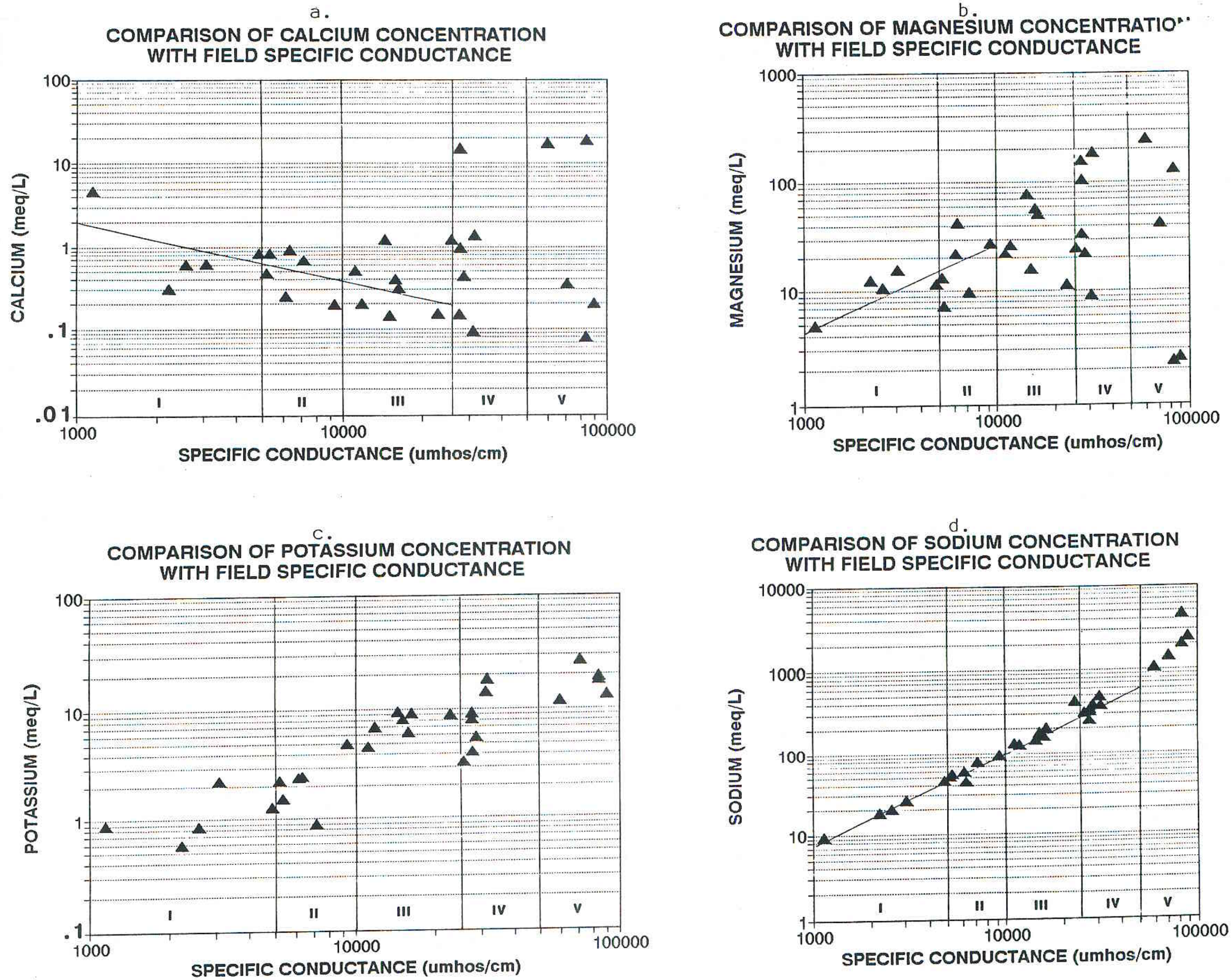

Figure 5. Comparison of the $\log_{10}$ concentrations of major cations with the $\log_{10}$ SC; a) calcium, b) magnesium, c) potassium, and d) sodium. Grouping of lakes based on SC are depicted by Roman numerals I through V.

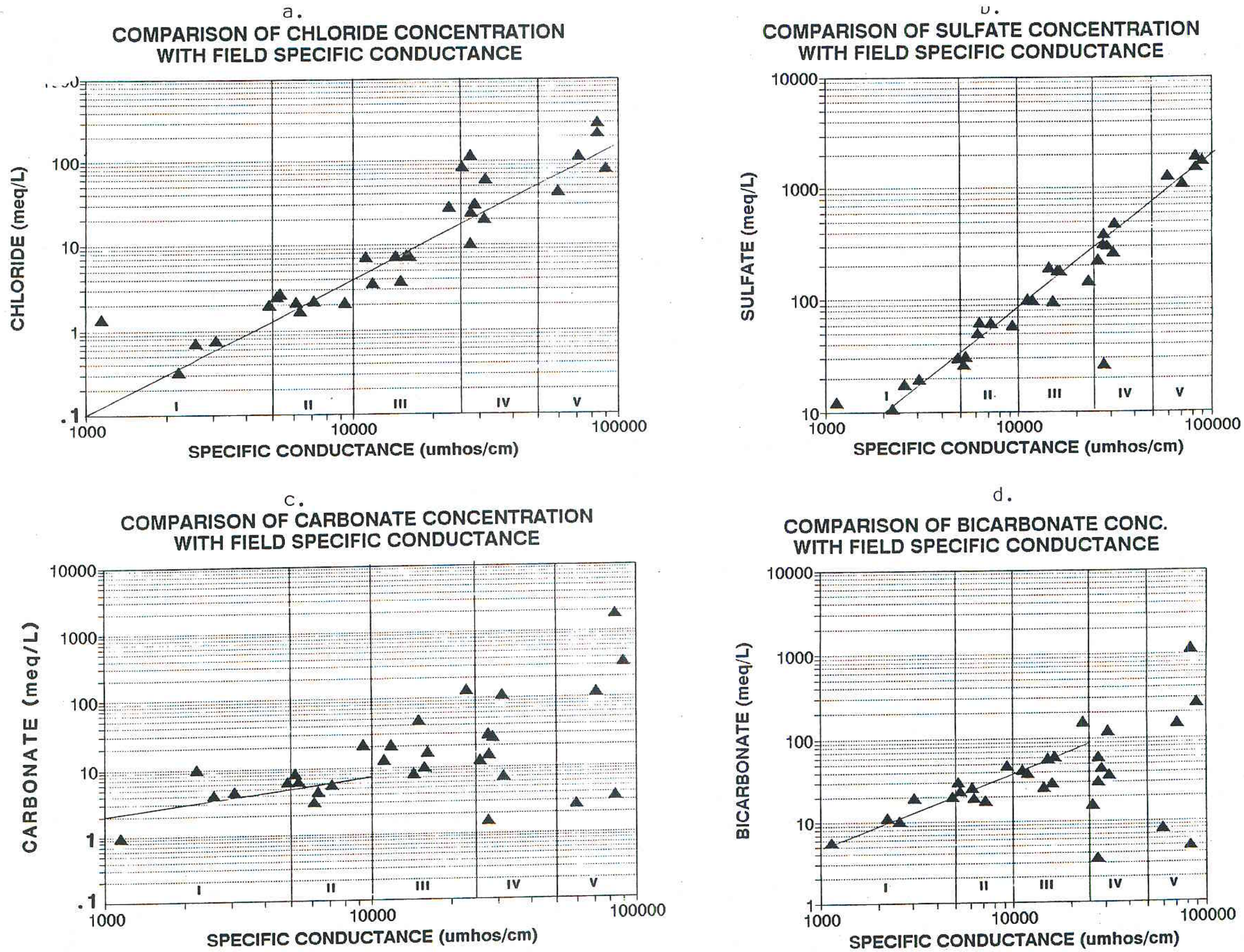

Figure 6. Comparison of the $\log_{10}$ concentrations of major anions with the $\log_{10}$ SC; a) chloride, b) sulfate, c) carbonate, and d) bicarbonate. Grouping of lakes based on SC are depicted by Roman numerals I through V.

A slight increasing trend of magnesium concentration with SC shown by the best fit line can be observed in Group I and Group II waters. The increased variability of magnesium concentration within Group III, Group IV, and Group V water masks any further trend. There is less of tendency for magnesium depletion due to carbonate precipitation than there was for calcium.

The $\log_{10}$ relationship between potassium concentration and SC is nearly linear, and it is similar to the relationship between sodium and SC (Figure 5c). However, the concentration of potassium is about one order of magnitude less than sodium in the freshest waters and about 2 orders of magnitude less than sodium in the most mineralized waters. Similar processes for potassium and for sodium result in the observed relationships including availability of potassium in the soils, solubility of potassium, and increased concentration of potassium caused by the arid climate.

The $\log_{10}$ relationship between sodium concentration and SC is approximately linear, with sodium steadily increasing as the water becomes more mineralized (Figure 5d). The steady increase in sodium reflects the accumulation of sodium salts in the soils of the region and the high solubilities of the sodium salts. Both abundance of sodium in the glacial deposits and the aridity of the climate influence the accumulation of sodium in the areas soils and eventually in the lakes.

The $\log_{10}$ relationship between chloride concentration and SC is approximately linear with chloride steadily increasing as the water becomes more mineralized (Figure 6a). The variability of the data points is largest in Group IV lake water. Chloride salts tend to be a minor component of near surface sediments and soils in this region. Data points plotting significantly above the best fit trend line may indicate water contaminated by chloride-rich brines. The general trend of increasing chloride concentration as the lakes become more mineralized probably is the result of evaporation concentrating the very soluble chloride salts in lakes with limited flow.

The $\log_{10}$ relationship between sulfate concentration and SC is approximately linear with sulfate steadily increasing as the water becomes more mineralized (Figure 6b). The steady increase in sulfate mirrors the sodium increases shown in Figure 5c. Sulfate is derived from the oxidation of pyrite and other sulfide minerals in the near surface sediments. It commonly accumulates as very soluble sodium sulfate salts resulting in the similarity between increases in sodium and sulfate concentrations as the lake water becomes more mineralized.

The $\log_{10}$ relationship between carbonate concentration and SC is again approximately linear but the linear trend becomes less evident above conductivities of 10,000 umhos/cm (Figure 6c). Similar to bicarbonate, the carbonate ions are depleted in the lake water as a result of marl deposition.

The $\log_{10}$ relationship between bicarbonate concentration and SC is approximately linear up to concentrations of 25,000 umhos/cm (Group I through Group III water) (Figure 6d). Below an SC of 25,000 umhos/cm the bicarbonate concentration increases as the water becomes more mineralized. Above an SC 25,000 umhos/cm the variability of bicarbonate concentration masks any linear trend. As lakes become supersaturated with bicarbonate ions, calcium carbonate marls are deposited depleting both of these ions from the dissolved minerals in the lake water.

Dissolved trace constituents in the sampled lakes generally fall into 3 categories based on trends of their concentrations. The majority of these elements are found in very low concentrations, usually below detection limits. Constituents fitting into this category include silver, cadmium, chromium, molybdenum, nickel, selenium, titanium, zinc, and zirconium. Other constituents including aluminum, barium, copper, lead, strontium, and vanadium were found in a relatively wide range of concentrations (Figure 7). Comparisons of the $\log_{10}$ concentrations of these constituents with $\log_{10}$ SC do not show any well developed trends. The final group of trace constituents includes arsenic, boron, bromide, and lithium (Figure 8). Comparing the $\log_{10}$ SC shows a linear trend of increasing concentration with increasing mineralization of lake water.

WATER QUALITY CHANGES DURING THE 1980'S

A lake water quality survey was conducted in September 1984 as part of hydrogeologic investigations in northeastern Montana (Donovan, 1988). The survey consisted of SC measurements from lakes in the Medicine Lake swale and the Clear Lake swale between Westby and Medicine Lake. Many of these same lakes were again sampled in August 1990, resulting in the water quality comparisons listed in Table 4. A total of 22 of the originally surveyed lakes were re-sampled. Where several field samples were collected in different parts of the larger lakes, the mean SC values and standard deviations were compiled for the comparison. Smaller lakes typically only had one measurement. Based on SC, lake water quality deteriorated in 20 of the 22 lakes surveyed.

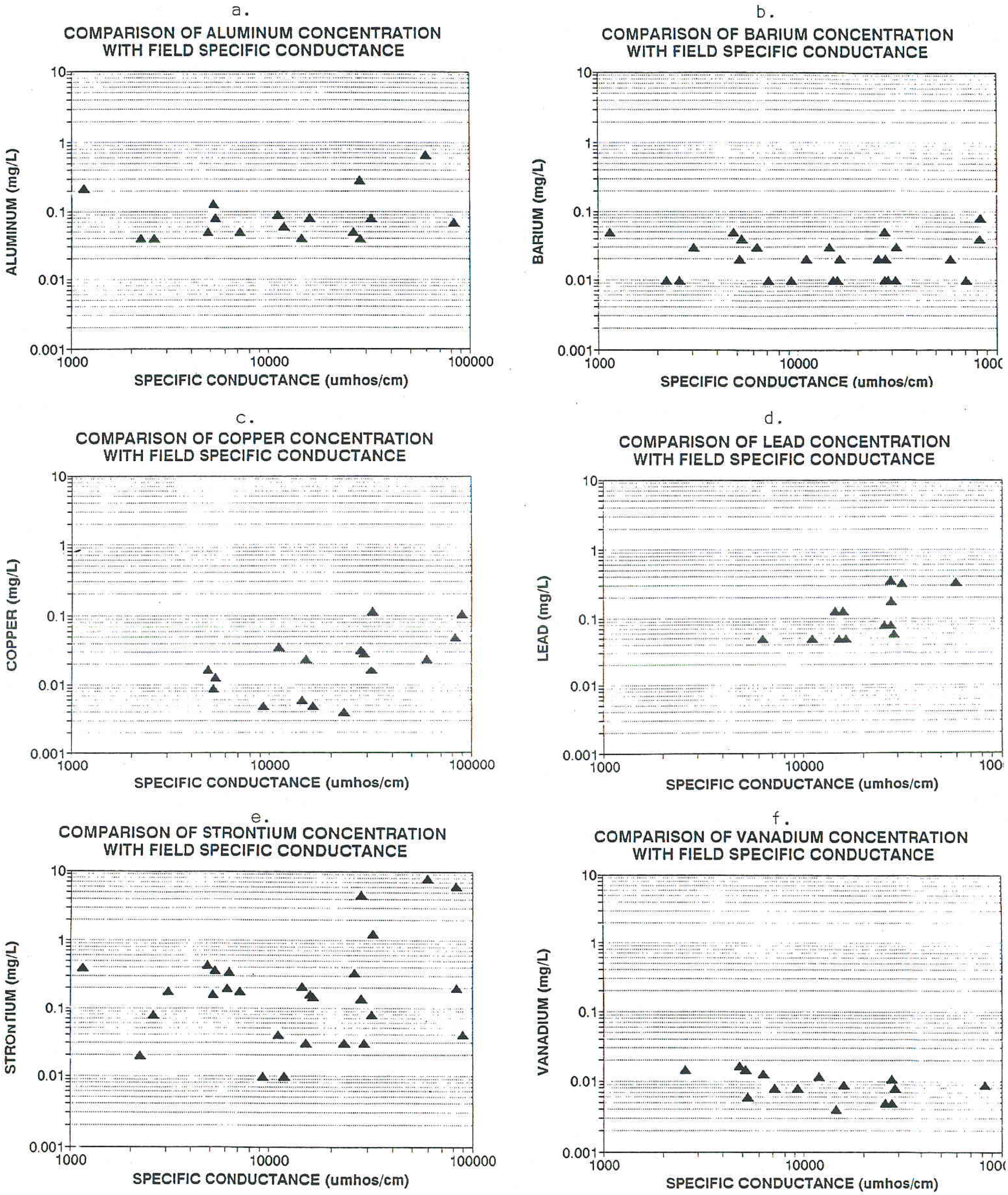

Figure 7. Comparison of the $\log_{10}$ concentrations of a) aluminum, b) barium, c) copper, d) lead, e) strontium, and f) vanadium with $\log_{10}$ SC.

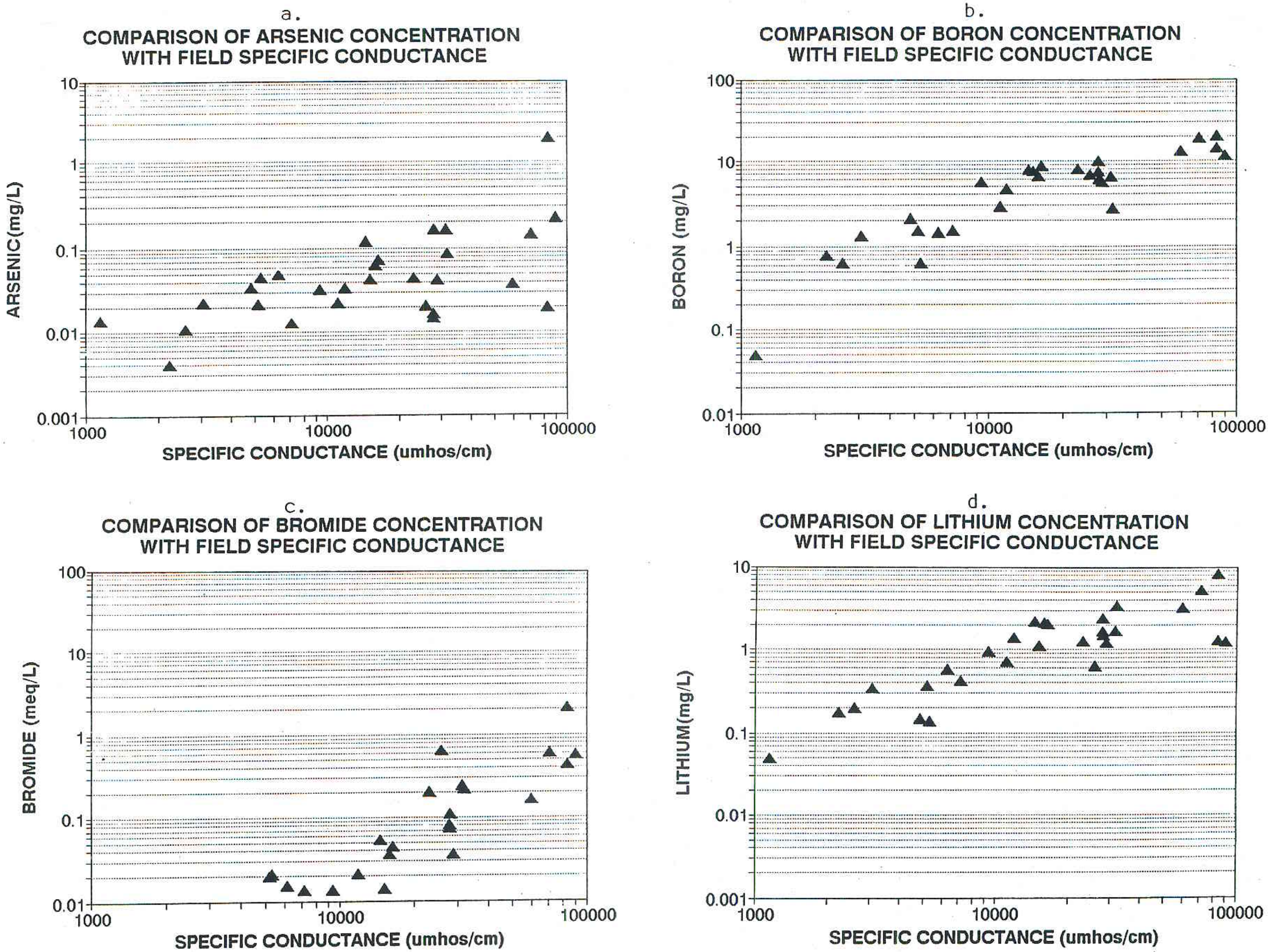

Figure 8. Comparison of the $\log_{10}$ concentrations of a) arsenic, b) boron, c) bromide, and d) lithium with $\log_{10}$ SC.

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990**

August 1990 Survey | **Lake Name** / Location | **September 1984 Survey**

South Westby Lake
T. 36 N., R. 58 E., Sec. 24 DADD

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	*SC (umhos)
A	89,900	2	1	56,092
			2	52,650
			3	59,032
			** $\bar{X}$ =	55,920
			*** sd =	3,194

Change in SC 1984 - 1990 = **+33,980** umhos
Percent change in SC = **61%** increase

Northwest Goose Lake
T. 36 N., R. 58 E., Sec. 26 CBAD

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	83,300		Dry	

Mudcrack Lake
T. 36 N., R. 58 E., Sec. 34 B

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	27,690	1	1	56,200

Change in SC 1984 - 1990 = **-28,510** umhos
Percent change in SC = **51%** decrease

Goose Lake
T. 35 N., R. 58 E., Sec., 1, 11, 12, 13
T. 36 N., R.58 E., Sec. 25, 36

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A South	21,000	2	1 North	31,450
B South	28,790	6,7	2 South	17,370
B South	28,740	6,7	3 South	29,670
C North	70,800	1	4 South	27,890
D North	70,940	5	5 North	26,700
F South	69,340	4	6 South	28,190
			7 South	27,600

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey			**Lake Name** Location	**September 1984 Survey**	
			Goose Lake (Continued)		
Combined $\bar{X}$ = 48,270 sd = 24,370				Combined $\bar{X}$ = 27,000 sd = 4,510	
North Lake $\bar{X}$ = 70,870 sd = 100				North Lake $\bar{X}$ = 29,080 sd = 3,360	
South Lake $\bar{X}$ = 36,970 sd = 21,890				South Lake $\bar{X}$ = 26,140 sd = 4,970	
			Combined lake change in SC 1984 - 1990 = **+21,270** umhos		
			Combined lake percent change in SC = **78%** increase		
			North lake change in SC 1984 - 1990 = **+41,790** umhos		
			North lake percent change in SC = **144%** increase		
			South lake change in SC 1984 - 1990 = **+10,830** umhos		
			South lake percent change in SC = **41%** increase		
			Beehive Lake T. 35 N., R. 58 E., Sec. 13 AADC		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	11,150	2		1	4,790
				2	4,980
				$\bar{X}$ =	4,885
				sd =	134
			Change in SC 1984 - 1990 = **+6,265** umhos		
			Percent change in SC = **128%** increase		
			Clear Lake T. 34 N., R. 58 E., Sec. 32, 33 T. 33 N., R. 58 E., Sec. 4, 5		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	8,690	1		1	5,890
B	11,900	2		2	6,090
C	12,020	3		3	6,390
$\bar{X}$ =	10,870			$\bar{X}$ =	6,120
sd =	1,890			sd =	252
			Change in SC 1984 - 1990 = **+4,750** umhos		
			Percent change in SC = **78%** increase		

TABLE 4. LAKE WATER QUALITY COMPARISON 1984-1990 (continued)

August 1990 Survey			Lake Name Location	September 1984 Survey	
			Beer Bottle Lake T. 35 N., R 58 E., Sec. 22 AB		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	15,890	1		1	10,940
				2	11,130
				$\bar{X}$ =	11,035
				sd =	134
			Change in SC 1984 - 1990 = **+4855** umhos Percent change in SC = **44%** increase		
			Brush Lake T. 35 N., R. 58 E., Sec. 22		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	6,140	2		1	5,810
				2	5,660
				3	5,360
				$\bar{X}$ =	5,610
				sd =	229
			Change in SC 1984 - 1990 = **+530** umhos Percent change in SC = **9%** increase		
			Horseshoe Lake T. 33 N., R. 58 E., Sec. 2 24 DDDA		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A (8/23/90)	72,750			1	63,500
A (8/30/90)	83,400			2	63,216
$\bar{X}$ =	78,080			$\bar{X}$ =	63,360
sd =	7,530			sd =	200
			Change in SC 1984 - 1990 = **+14,720** umhos Percent change in SC = **23%** increase		
			East White Lake T. 33 N., 58 E., 26 BADD		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	14,500	1		1	10,960
				2	10,960
			Change in SC 1984 - 1990 = **+3,540** umhos Percent change in SC = **32%** increase		

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey			**Lake Name** Location	**September 1984 Survey**	

Horsefly Lake
T. 33 N., R. 58 E., Sec. 27 AABB

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	27,800	1	1	34,390

Change in SC 1984 - 1990 = **-6,590** umhos
Percent change in SC = **19%** decrease

West White Lake
T. 33 N., R. 58 E., Sec. 27 ACBC

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	16,420	2	1	7,150
			2	6,940
			$\bar{X}$ =	7,045
			sd =	148

Change in SC 1984 - 1990 = **+9,375** umhos
Percent change in SC = **133%** increase

Betty Lake
T. 33 N., R. 58 E., Sec. 27 CBCC

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A (8/22/90)	9,670		1	4,600
A (8/24/90)	9,350			
B	8,990			
C	9,660	1		
$\bar{X}$ =	9,420			
sd =	320			

Change in SC 1984 - 1990 = **+4,820** umhos
Percent change in SC = **105%** increase

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey		**Lake Name** Location	**September 1984 Survey**	

Teresa Lake
T. 33 N., R. 58 E., Sec. 28 C

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A(8/22/90)	16,190	1	1	7,510
A(8/24/90)	15,120	1	2	6,980
B	15,990	2		
$\bar{X}$ =	15,770		$\bar{X}$ =	7,250
sd =	569		sd =	375

Change in SC 1984 - 1990 = **+8,520** umhos
Percent change in SC = **118%** increase

John Lake
T. 33 N., 58 E., Sec. 29 D

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	3,070	1	1	2,555
B	3,260	2	2	2,767
$\bar{X}$ =	3,165		$\bar{X}$ =	2,660
sd =	134		sd =	150

Change in SC 1984 - 1990 = **+505** umhos
Percent change in SC = **19%** increase

Mallard Pond
T. 33 N., R. 58 E., Sec. 33 B

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	1,475		Not Sampled	<2,000 (Est)
B	2,610			
C	2,590			
$\bar{X}$ =	2,220			
sd =	650			

Black Water Lake
T. 35 N., R. 58 E., Sec. 33 C

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	88,700		Not sampled	DRY

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey | **Lake Name** / Location | **September 1984 Survey**

Long Lake
T. 33 N., R. 58 E., Sec. 32
T. 32 N., R. 58 E., Sec. 2, 3

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	5,360	1	1	4,070
B	5,370	3	2	4,390
C	5,440	2	3	4,240
D	5,200			
$\bar{X}$ =	5,340		$\bar{X}$ =	4,230
sd =	101		sd =	160

Change in SC 1984 - 1990 = **+1,110** umhos
Percent change in SC = **26%** increase

Fred Lake
T. 32 N., R. 58 E., Sec. 4 DA

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A(8/22/90)	2,300		1	1,790
A(8/24/90)	2,230		2	1,770
B	2,260	1		
C	2,190			
D	2,280	2		
$\bar{X}$ =	2,250		$\bar{X}$ =	1,780
sd =	43		sd =	14

Change in SC 1984 - 1990 = **+470** umhos
Percent change in SC = **26%** increase

Berger Pond
T. 32 N., R. 58 E., Sec. 9 A and 10 B

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	24,440	2	1	1,725
B	22,990	3	2	18,080
			3	17,900
$\bar{X}$ =	23,720		$\bar{X}$ =	17,740
sd =	1,025		sd =	437

Change in SC 1984 - 1990 = **+5,980** umhos
Percent change in SC = **34%** increase

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey			**Lake Name** Location	**September 1984 Survey**	

No. 12 Lake
T. 32 N., R. 57 E., Sec. 4, 13
T. 32 N., R. 58 E., Sec. 8, 9, 18

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A	5,100	1	1	2,230
B (8/22/90)	4,210		2	3,180
B (8/24/90)	6,300		3	2,390
C	5,190		4	3,014
D	5,545		5	3,540
E	6,300	2		
F	5,610	3		
G	4,750	5		
H	5,910			
$\bar{X}$ =	5,440		$\bar{X}$ =	2,870
sd =	700		sd =	549

Change in SC 1984 - 1990 = **+2,570** umhos
Percent change in SC = **90%** increase

Katy Lake
T. 32 N., R. 58 E., Sec. 17

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
A (8/22/90)	20,000	1	1	12,810
A (8/24/90)	31,190	1	2	12,620
$\bar{X}$ =	25,600		$\bar{X}$ =	12,720
sd =	7,910		sd =	134

Change in SC 1984 - 1990 = **+12,880** umhos
Percent change in SC = **101%** increase

Deep Lake
T. 32 N., R. 57 E., Sec. 32 B

Sample Point	SC (umhos)	Similar 1984 Sample Point	Sample Point	SC (umhos)
I	5,340	1	1	4,459
			2	4,621
			$\bar{X}$ =	4,540

Change in SC 1984 - 1990 = **+800** umhos
Percent change in SC = **18%** increase

TABLE 4. **LAKE WATER QUALITY COMPARISON 1984-1990 (continued)**

August 1990 Survey			**Lake Name** Location	**September 1984 Survey**	
			Gaffney Lake T. 31 N., R. 57 E., Sec. 3, 4 T. 32 N., R. 57 E., Sec. 32, 33		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
H	4,870	4		1	2,990
				2	3,100
				3	3,232
				4	3,075
				$\bar{X}$ =	3,100
				sd =	100
			Change in SC 1984 - 1990 = **+1,770** umhos Percent change in SC = **57%** increase		
			Medicine Lake T. 31 N., R. 56, 57 E. T. 32 N., R. 56, 57 E.		
Sample Point	SC (umhos)	Similar 1984 Sample Point		Sample Point	SC (umhos)
A	4,690	2		1	2,290
B	650	1(Big Muddy Diversion)		2	2,354
C	4,180	1		3	1,782
D	4,420			4	2,227
E	4,580			5	3,053
F	4,760	9		6	1,678
G	4,320	8		7	1,637
J	4,670	4		8	1,590
				9	1,650
				10	2,327
$\bar{X}$ =	4,030			$\bar{X}$ =	2,060
sd =	1,380			sd =	473
			Change in SC 1984 - 1990 = **+1,970** umhos Percent change in SC = **96%** increase		

* SC refers to the specific conductance of a lake water sample

** $\bar{X}$ refers to the mean (average) SC of water samples from a specific lake

*** sd refers to the Standard Deviation (dispersion about the mean) of the accumulated SC data

The percent of water quality change ranged from +19 percent to +96 percent in Group I lakes; from +9 percent to +105 percent in Group II lakes; from +32 percent to +128 percent in Group III lakes; and from +23 percent to +61 percent in Group V lakes. The only lakes showing water quality improvement were two Group IV lakes where SC decreased 19 percent and 51 percent respectively while two of the Group IV lakes had SC increases of 23 percent and 61 percent respectively. In summary , no clear trends of water quality changes are apparent based on lake water quality category, lake size, or geographic position of the lakes.

The most likely cause of the overall water quality deterioration is the result of the prevailing drought conditions during the 1980's. Reduced precipitation produced less direct runoff into the lakes and less recharge into the ground water system feeding into the lakes. The drought was accompanied by high evaporation rates further concentrating dissolved constituents into the lake water. The decrease in lake volume was not accompanied by a uniform decrease in the mass of dissolved minerals. While decreased rainfall and runoff would also decrease the mass of dissolved constituents brought into the lakes, most of the dissolved minerals (largely sodium sulfate salts) are highly soluble and do not precipitate until highly concentrated brines have formed. As a result, the SC and calculated dissolved solids have in general, increased during the 1980's. Measurements at Medicine Lake by the U.S. Fish and Wildlife Service indicate a change in the lake water level from 1.28 feet below desired management level to 3.99 feet below desired management level between September 1984 and August 1990, confirming the impacts of the drought.

The two lakes showing water quality improvements were Mudcrack Lake and Horsefly Lake. The cause of the decrease in salinity is unclear. Local variabilities in where the samples were collected may have caused the anomalous freshening of the lake waters. Mudcrack Lake appears to have been impacted by oil-field brines and perhaps some of the sodium chloride salts have been removed from the basin since the first sample was collected. Possible methods of salt removal include flushing and dilution by rainfall and run-off, or by the wind blowing salt crystals out of the basin when the lake was dry.

EVIDENCE OF CONTAMINATION

While the intent of compiling background water quality samples was to identify baseline conditions in the region, existing uses may have already impacted lake water quality. Two likely activities that may have potentially impacted the water resources are farming and oil field development.

Evidence of farming impacts to water quality were not apparent based on the results of these water analyses. High levels of nitrates and phosphates would be the most obvious impacts if large quantities of animal wastes or fertilizers had been flushed into these lakes. Relatively low concentrations of nitrates and phosphates were identified in all of the lakes sampled. The high concentrations of dissolved oxygen in many of the lakes are probably the result of high algal activity and photosynthesis. It is possible that nutrients may be increasing the algal production in some of the lakes. But these lakes are probably naturally

eutrophic
~~oligitrophi~~c, and impacts from agriculture are probably insignificant.

There is stronger evidence for impacts to water quality from oil field wastes. Large volumes of highly concentrated sodium chloride brines have been pumped to the land surface since the early 1960's. The brines are associated with oil producing zones and are produced along with the oil. Shallow ground water contamination by sodium chloride salts has been identified in the vicinity of many of these lakes (Reiten and Tischmak, in press). Occasionally chloride levels increase along with dissolved solids and SC due to evaporation in surface-water bodies. To distinguish between naturally-elevated chloride concentrations and those elevated by impacts of oil field brines, a contamination index (CI) was designed. For field applications, this index is defined as the ratio of field chloride concentration to field SC. Previous work in eastern Sheridan County developed an empirical lower limit indicating brine impacts at CI = 0.035. Based on this limit and the data compiled in Table 2 twenty-five lakes appear to have been impacted by brines. Although valid over wide ranges of water quality, the index tends to be less effective for predicting contamination in highly mineralized waters. In highly mineralized waters, SC loses its linear relationship with calculated dissolved solids and typically under predicts the concentration of dissolved minerals. Under these conditions the contamination index will improperly indicate contamination.

A more accurate index can be developed when complete water analyses are run on the lake water samples. Comparing the percent millequivalents of chloride of the total anions from different lakes can also indicate the relative magnitude of brine impacts. The empirical limit of percent millequivalents chloride set as an indicator of brine contamination is 5.5%. Using this limit, brine impacted lakes and associated percentage of chloride ions by lake are Mudcrack Lake- 27%, Football Lake - 25.2%, Northwest Goose Lake - 13.2%, Lone Tree Lake - 10.1%, North Goose Lake - 7.8%, South Goose Lake - 7.4%, Larson Slough - 6.9%, and Berger Pond - 5.9%.

Impacts to Mudcrack Lake, Northwest Goose Lake, North Goose Lake, and South Goose Lake all appear to be related to sources of contamination in the Goose Lake oilfield that were identified in a previous study (Reiten and Tischmak, in press). Environmentally unsound methods of brine disposal that were commonly used at these sites prior to 1975 are the main causes of the existing contamination. The use of evaporation pits, trenching of reserve pits, and pipeline leaks all have contributed to the brine contamination. It is unlikely that the large extent and high level of surface-water and ground-water contamination existing in the Goose Lake Field could be derived from these relatively small volume sources of brine. Much of the existing contamination appears to confirm landowner reports that large volumes of brine were disposed of by simply allowing the brine to flow onto the ground surface. Similar brine disposal methods probably account for the contamination of other impacted lakes in the region.

CONCLUSIONS

Lake water in eastern Sheridan County covers a range from fresh to highly mineralized. The lakes were classified on the basis of specific conductance (SC) into 5 groups; Group I 0-5,000 umhos/cm, Group II 5,000-10,000 umhos/cm, Group III 10,000-25,000 umhos/cm, Group IV 25,000 - 50,000 umhos/cm and Group V >50,000 umhos/cm. In spite of this diversity in water quality, the water in these lakes is relatively uniform in proportions of major cations and anions. Sodium and sulfate are the dominant ions in the regions lake water. This dominance is probably the result of the availability of these constituents in near surface geologic sediments and high solubilities of sodium sulfate salts. The aridity of this region also accounts for concentrating these salts in the soil and lake water. The ranking of cation concentrations is NA > MG > CA and for anion concentrations is SO_4 > HCO_3 + CO_3 > CL for all five water groups.

Lake water quality in general declined from September 1984 to August 1990 based on conductivity surveys conducted on 22 lakes between Westby and Medicine Lake. No clear trends of water quality changes were apparent based on lake water quality category, lake size, or geographic position of the lakes. Drought conditions during the 1980's appears to have decreased the volume of water in the lakes while the mass of dissolved solids remained relatively stable causing the increase in SC.

The water quality information does not indicate any negative impacts to lake water from agricultural activities. In contrast, the levels of chloride concentrations in several of the lakes are probably the result of improper disposal of oil field brines. The use of evaporation pits, trenching of reserve pits, pipeline leaks and other environmentally unsound methods of brine disposal are the main causes of the existing contamination. While many of these problems are actually related to site specific releases, the extent, diversity and large number of sites create a nonpoint-source effect of the brine contamination.

Considerable evidence exists implicating oilfield brines as the cause of high chloride concentrations in several of the lakes sampled. However, the levels of degradation have not impacted the lakes to the extent that shallow aquifers have been impacted. The high concentrations of other soluble salts tends to limit the uses of many of the lakes regardless of the observed influx of chloride salts. The relatively slow velocities of ground-water flow may account for concentrating the brine contamination in the shallow aquifers. The main slug of brines may not have yet been discharged into the lakes. Periodic resampling of several of these lakes would be a reasonable means to monitor the extent and magnitude of degradation caused by oil field wastes.

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