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CHEMICAL CHARACTERISTICS OF SOME MISSOURI RESERVOIRS

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ABSTRACT: Chemical analyses of surface waters of 43 Missouri reservoirs were made in fall 1975. All major elements were estimated and good agreement was found between the sum of positive and sum of negative ions (both in meq/l) within each sample. Various chemical parameters showed wide variation among sampled reservoirs. Most had typical hard waters of the bicarbonate type. Chemical composition of waters differed among the four physiographic regions in Missouri. Reservoirs within the Osage Plains had higher values for all parameters measured. Values were lowest in the Southeastern Lowlands with intermediate concentrations found in the Ozark Uplands and Dissected Till Plains. Similar regional differences were found in the composition of river waters in Missouri.

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Introduction. Studies of regional limnology in various lake districts have established the importance of chemical composition to separate lake types and provide background for interpreting biological differences (Armstrong and Schindler, 1971). In many areas the mineral composition of the lake water is determined by surface geology (Deevey, 1940; Moyle, 1956; Bachmann, 1965), but atmospheric precipitation and the evaporation-crystalization process are also controlling mechanisms (Gibbs, 1970). A regional limnology survey was designed to provide similar information of the surface waters in Missouri. The objectives were (1) to determine the chemical characteristics of waters selected as being geographically representative of Missouri impoundments, and (2) to determine if waters differ in chemical composition among the four physiographic regions of Missouri (Figure 1) (Fenneman, 1938). Major cations and anions were measured during a 6-week period (11 October 1975 to 22 November 1975). By measuring conservative elements during a short sampling period, seasonal fluctuations were considered minimal. Emphasis was placed on waters located in state parks and areas managed by the Missouri Department of Conservation (Figure 1).

Methods. Surface water samples were collected in triplicate from several lakes on a single day with chemical analyses completed within the next 2-4 days. Specific conductance was measured with a Radiometer Measuring Instruments type CDM2e conductivity meter corrected for temperature effects and reported as micromhos/cm at 25 C. Total alkalinity was determined by using brom cresol green-methyl red indicator titrated with 0.02N sulfuric acid. Total and calcium hardness concentrations were determined by complexometric titration with 1,2-cyclohexane-diaminetetraacetate-Hexa Ver^R (Hach Chemical Co., Ames, Iowa). Man Ver^R and Cal Ver II^R (Hach Chemical Co.) indicators were used for endpoint determinations. Chloride was determined by titration with mercuric nitrate using diphenol carbazone indicator-buffer power (Hach Chemical Co.). Sulfate was determined turbidimetrically by using Sulfa Ver^R IV (Hach

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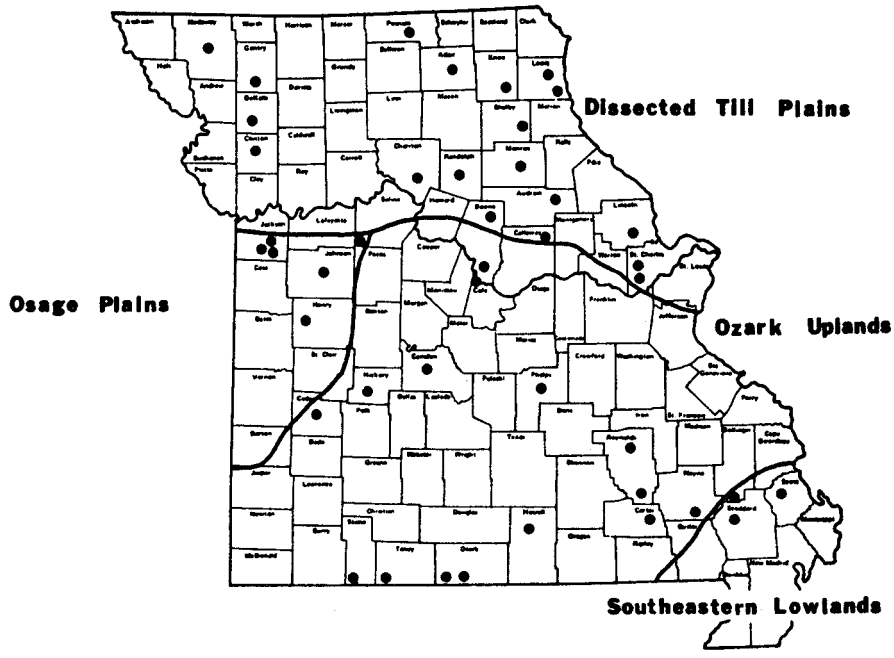

Figure 1. Location of lakes sampled in this study. Lines separate physiographic regions in Missouri.

Chemical Co.). Sodium and potassium concentrations were determined on samples filtered through a type HA 0.45 μg Millipore filter by using a Jarrell-Ash 0.5 m spectrophotometer and associated electronics with an air-acetylene flame emission. Values were corrected for the 1.0 ml of 1000 mg La/l added to each sample as $LaCl_3$.

Calcium and magnesium concentrations were calculated using total and calcium hardness values.

Results—Discussion. Results of the chemical analyses are summarized in Table 1. Values represent the mean of three samples collected from each lake. In general, ion concentrations ($Ca > Mg > Na > K$ and $HCO_3 > SO_4 > Cl$) of waters in Missouri reservoirs are typical of most natural freshwaters (Rodhe, 1949). Exceptions were found in Montrose and Thomas Hill reservoirs where SO_4 is the predominate anion. Coal mining within both watersheds is the likely source of these high SO_4 concentrations (Brezina, *et al.*, 1970). Other minor exceptions were noted in proportions of ions in some lakes which could not be explained by watershed characteristics. Agreement between positive and negative ions (as meq/l) in an ion balance of major elements in each lake was within the range found acceptable by Golterman (1969). And there is a good correlation between total concentration of cations or anions (as meq/l) and specific conductance ($r = 0.99$, $P = 0.01$).

Table 1. Chemical analyses of surface waters from 43 Missouri reservoirs located in the Dissected Till Plains (TP), Osage Plains (OP), Ozark Uplands (OU) and Southeastern Lowlands (SL). Collections made between 11 October and 22 November, 1975.[a]

Location	Specific Conductance Micromhos/cm at 25 C	Alkalinity as mg/l $CaCO_3$	Total hardness as mg/l $CaCO_3$	Calcium mg/l	Magnesium mg/l	Sodium mg/l	Potassium mg/l	Sulfate mg/l	Chloride mg/l	Physiographic Region
1. Ashland, Boone Co.	172	72	78	25	4	2	4	7	3	OU
2. August A. Bush #34, St. Charles Co.	295	103	114	29	10	14	3	17	15	TP
3. August A. Bush #35, St. Charles Co.	195	58	67	20	4	11	3	14	12	TP
4. Binder, Cole Co.	272	98	119	24	14	6	4	24	8	OU
5. Blind Pony, Saline Co.	303	106	130	38	8	8	5	35	6	OP
6. Bull Shoals, Ozark Co., MO Taney Co., AK	246	116	120	30	11	2	1	5	3	OU
7. Clearfork, Johnson Co.	256	91	116	36	6	5	2	35	2	OP
8. Clearwater, Reynolds Co.	280	130	141	29	17	3	1	10	3	OU
9. Deer Ridge, Lewis Co.	144	56	62	19	4	4	3	9	3	TP
10. Duck Creek, Bollinger Co.	49	19	20	4	2	1	2	2	2	SL
11. Forest, Adair Co.	316	104	136	44	1	6	3	36	5	TP
12. Henry Seaver, Knox Co.	212	74	91	27	6	6	4	21	6	TP

	Location	SC	Alk	Total	Ca	Mg	Na	K	SO_4	Cl	Area
13.	Hunnewell, Shelby Co.	152	63	67	21	3	3	4	9	3	TP
14.	Jacomo, Jackson Co.	303	109	122	39	6	11	3	20	13	OP
15.	Lake of the Ozarks, Camden and Miller Co.	275	107	125	34	10	5	3	23	5	OU
16.	Limpp, Gentry Co.	302	106	119	35	8	13	7	31	10	TP
17.	Lincoln, Lincoln Co.	183	78	87	30	3	3	1	12	2	TP
18.	Little Dixie, Callaway Co.	142	55	58	19	3	4	4	9	4	TP
19.	Little Prairie, Phelps Co.	107	31	42	8	5	3	2	13	3	OU
20.	Mark Twain, Monroe Co.	87	34	35	11	2	2	1	6	1	TP
21.	Miller, Carter Co.	23	5	7	2	1	1	1	4	1	OU
22.	Montrose, Henry Co.	842	70	352	87	32	39	10	311	6	OP
23.	Nodaway, Nodaway Co.	236	104	105	29	8	6	4	10	5	TP
24.	Norfork, Ozark Co.	390	204	206	42	23	4	2	4	3	OU
25.	Pomme de Terr, Hickory Co.	260	116	125	27	14	3	2	6	5	OU
26.	Pony Express, De Kalb Co.	206	84	89	27	5	5	4	13	4	TP
27.	Prairie Lee, Jackson Co.	374	120	140	45	7	19	3	24	22	OP
28.	Rockhouse, Stoddard Co.	104	38	39	8	5	3	3	3	4	SL
29.	Sims, Howell Co.	50	18	19	4	2	1	2	2	2	OU
30.	Sterling, Chariton Co.	194	76	81	24	5	4	4	7	5	TP

	Location	SC	Alk	Total	Ca	Mg	Na	K	SO_4	Cl	Area
31.	Stockton, Cedar Co.	266	116	125	39	7	2	2	9	5	OU
32.	Table Rock, Stone Co.	201	89	93	29	5	2	1	5	4	OU
33.	Taneycomo, Taney Co.	223	100	105	34	5	2	1	5	4	OU
34.	Tapawingo, Jackson Co.	297	111	121	41	5	11	3	17	13	OP
35.	Taum Sauk, Reynolds Co.	148	66	72	14	9	1	1	7	1	OU
36.	Thomas Hill, Macon Co.	373	63	149	43	10	10	3	89	4	TP
37.	Thunderhead, Putnam Co.	245	93	101	30	6	6	5	16	5	TP
38.	Tri City, Boone Co.	103	37	39	12	2	3	2	7	3	TP
39.	Trimble, Clay and Clinton Co.	244	102	109	33	6	6	4	15	4	TP
40.	Tywappity, Scott Co.	78	33	33	8	3	1	3	2	2	SL
41.	Vandalia, Audrain Co.	129	55	56	17	3	3	4	5	3	TP
42.	Wakonda, Lewis Co.	317	124	140	31	15	8	3	23	11	TP
43.	Wappapello, Wayne Co.	239	105	115	23	14	3	2	9	4	OU

[a]mean of three samples rounded to the nearest whole number

The mineral content of water in Missouri reservoirs varies over a wide range (Table 2). For most parameters the mean and median values are similar indicating a near normal distribution. The chemical composition of Nodaway Reservoir,

Table 2. Mean and standard error, median and range of water chemistry parameters measured on 43 Missouri reservoirs in fall 1975.

Parameter	Mean	Standard Error	Median	Range
Specific conductance micromhos/cm at 25 C	229	20.2	236	23 - 842
Total alkalinity as mg/l $CaCO_3$	82	5.7	89	5 - 204
Total hardness as mg/l $CaCO_3$	99	8.8	105	7 - 352
Calcium mg/l	27	2.3	29	1 - 87
Magnesium mg/l	7	0.9	6	1 - 32
Sodium mg/l	6	1.0	4	1 - 39
Potassium mg/l	3	0.3	3	1 - 10
Sulfate mg/l	22	7.2	10	1 - 311
Chloride mg/l	5	0.6	4	1 - 22

Nodaway Co., is representative of median concentrations in Missouri reservoirs (Table 1). Specific conductance, hardness, Ca, and SO_4 concentrations in Nodaway Reservoir are median values for the sampled reservoirs (Table 2) and concentrations of the other parameters are near median. The ionic concentration (in meq/l) of Montrose Reservoir is 50 times higher than Miller Reservoir (Table 1). These water bodies represent the extremes measured within the state. Eighty percent of the reservoirs sampled had alkalinities above 40 mg/1, the concentration used by Moyle (1956) to separate hard and soft water lakes in Minnesota. Values in Missouri are similar to the chemical range found in surface waters of other mid-continent states (Juday and Birge 1933; Lohuis, *et al.*, 1938; Moyle, 1956; Carlander, *et al.*, 1963; Bachmann, 1965).

To analyze for regional differences, data were separated by location into the four physiographic regions of Missouri (Table 1, Figure 1). The four regions are: (1) the Dissected Till Plains, including all of Missouri north of the Missouri River, the maximum limit of glaciation; (2) the Osage Plains, an unglaciated

plain in western Missouri; (3) the Ozark Uplands, elevated country lying in southeastern Missouri; (4) the Southeastern Lowlands, the northern extremity of the Mississippi Embayment, a vast alluvial plain. The physical features of these regions are described by Fenneman (1938) and Pflieger (1971). Mean values by region are given in Table 3. Data from Montrose and Thomas Hill reservoirs were eliminated from the analysis because of sulfuric acid pollution from the strip mines within the watersheds (Brezina, *et al.*, 1970).

Table 3. Mean water chemistry values of reservoir waters within the four physiographic regions of Missouri.[a]

Parameter	Physiographic Region			
	Dissected Till Plains (N = 18)	Osage Plains (N = 5)	Ozark Uplands (N = 15)	Southeastern Lowlands (N = 3)
Specific conductance micromhos/cm at 25 C	206	307	211	77
Total alkalinity as mg/l $CaCO_3$	78	107	92	30
Total hardness as mg/l $CaCO_3$	86	126	99	31
Calcium mg/l	25	40	24	7
Magnesium mg/l	6	6	9	3
Sodium mg/l	6	11	3	2
Potassium mg/l	3	3	2	2
Sulfate mg/l	14	26	9	3
Chloride mg/l	6	11	4	2

[a]Data from Montrose and Thomas Hill reservoirs are omitted.

Analysis of variation in sample values among lakes within any region indicated that lakes were a significant source of variation compared to sampling error ($P > 0.025$); the one exception was significant inherent variation for SO_4 among lakes in the Southeastern Lowlands. Thus, means were used to represent parameters for any given lake. Further analysis indicated that variation in the value of any parameter among lakes within a region was dominated by significant variation among regions ($P > 0.025$). Independent t-tests were used to further

test differences of mean chemical concentrations among the four physiographic regions (Table 4). The comparisons made were: (1) the Southeastern Lowlands vs the means of the three other regions, (2) the Osage Plains vs the mean of the Dissected Till Plains and Ozark Uplands, and (3) the Dissected Till Plains vs the Ozark Uplands.

Table 4. Results of t-tests of mean water chemistry values measured in reservoirs located on the Dissected Till Plains, the Osage Plains, the Ozark Uplands and the Southeastern Lowlands.[a]

	Comparisons of:		
Parameter	Southeastern Lowlands vs Dissected Till Plains, Osage Plains, Ozark Uplands	Osage Plains vs Dissected Till Plains Ozark Uplands	Dissected Till Plains vs Ozark Uplands
Specific conductance micromhos/cm at 25 C	X	X	
Total alkalinity as mg/l $CaCO_3$	X		
Total hardness as mg/l $CaCO_3$	X		
Calcium mg/l	X	X	
Magnesium mg/l			X
Sodium mg/l	X	X	X
Potassium mg/l			X
Sulfate mg/l	X	X	
Chloride mg/l		X	

[a] X indicates significant difference at P = 0.01.

Collectively, reservoirs in the Southeastern Lowlands have the lowest ion concentrations found within the four physiographic regions. Only Mg, K, and Cl concentrations did not differ significantly from other surface waters measured (Table 3). Mineral content is generally greatest in the Osage Plains region. Specific conductance, Ca, Na, SO_4 and Cl values were highest in this region. Reservoirs in the Dissected Till Plains and Ozark Uplands are chemically similar. Waters in the Dissected Till Plains have significantly lower Mg concentrations and significantly higher Na and K concentrations than in the Ozark Uplands.

Similar results were obtained in comparisons of published water chemistry values from rivers within three of the physiographic regions (U.S.G.S., 1974) (Table 5). Water chemistry data was not available from rivers in the Osage Plains to make comparisons. An analysis of variance test indicated that for all parameters difference among rivers within a region was dominated by the significant variation among regions ($P > 0.025$). Independent t-test comparisons among the Southeastern Lowlands, Ozark Uplands and Dissected Till Plains rivers are identical to reservoir comparisons except SO_4 and Cl concentrations were significantly greater in the Dissected Till Plains than the Ozark Uplands and Mg concentrations were not significantly different between these regions (Table 6). Rivers tend to have higher ion concentrations than reservoirs within each of the regions.

Differences in mineral content of waters among physiographic regions in Missouri can be related to the water-bearing earth materials in these areas. Because surface streams and ground waters are inter-connected, comparisons of ground water quality within the state are similar to the surface waters (Stout and Hoffman, 1973). The softest waters within the state are associated with the McNairy sands in the Southeast Lowlands. In the Osage Plains, high concentrations of dissolved substances can be ascribed to the low permeability of shales in this region and thus the long residence time of ground water. Similar to the surface waters, ground waters in the Osage Plains contain the highest concentrations of Na, SO_4 and Cl within the state. The calcium-magnesium bicarbonate waters of the Dissected Till Plains and, the Ozark Uplands are typical of hard waters associated, respectively, with glacial outwash sediments and carbonate-sandstone bedrock (Stout and Hoffman, 1973).

The biological significance of differences in water chemistry found among the physiographic regions of Missouri is unknown. Pflieger (1971) found the distribution of Missouri fishes can be separated into faunal regions which correspond closely to major physiographic subdivisions. Physical characteristics (such as temperature, flow, turbidity, and bottom type) and competition among species are important factors controlling fish distribution (Pflieger, 1971). The gradients in these environmental factors likely obscure any possible effects of water chemistry. Aquatic production, however, would be expected to differ among Missouri reservoirs based upon morphometric differences and the wide range of total ion concentration and alkalinity (Moyle, 1956: Ryder *et al.*, 1974).

The foregoing relationship between water chemistry and the four physiographic regions within Missouri should be considered a holistic approach to explain the observed differences and similarities in chemical content among surface waters within the physiographic regions. Because of variation in chemical concentrations among lakes within each region this relationship should be used with caution as a basis for comparing the chemical composition of individual water bodies within or between regions.

Table 5. Mean water chemistry of rivers in the Dissected Till Plains, Ozark Uplands and Southeastern Lowlands.[a]

Location	Specific Conductance micromhos/cm at 25 C	Total Alkalinity as mg/l $CaCO_3$	Total Hardness as mg/l $CaCO_3$	Calcium mg/l	Magnesium mg/l	Sodium mg/l	Potassium mg/l	Sulfate mg/l	Chloride mg/l
Dissected Till Plains									
North River, Marion Co.	384	135	194	53	10	9	4	42	8
Salt River, Ralls Co.	341	102	136	43	8	12	4	41	12
Cuivre River, Lincoln Co.	346	128	153	48	8	7	4	27	8
Nodaway River, Holt Co.	397	158	185	52	13	11	3	36	8
Platte River, Platte Co.	393	156	177	53	11	12	4	36	9
Thompson River, Livingston Co.	414	170	192	57	12	11	4	38	7
Grand River, Charlton Co.	382	155	175	54	10	10	4	34	6
Charlton River, Charlton Co.	300	99	136	40	9	8	4	47	5
E. Fork Charlton River, Macon Co.	315	100	132	39	9	12	3	48	6
Mean	363	134	164	49	10	10	4	39	8
Ozark Uplands									
Meramec River, Franklin Co.	300	147	156	32	18	3	1	9	3

	SC	Alk	Hard	Ca	Mg	Na	K	SO_4	Cl
Ozark Uplands									
Bourbeuse River, Franklin Co.	242	95	113	23	13	4	2	19	4
Big River, Jefferson Co.	400	190	202	43	23	4	1	18	4
Meramec River, Jefferson Co.	344	146	162	36	17	7	2	19	9
James River, Christian Co. near Wilson Creek, MO.	325	144	156	52	6	5	2	9	7
James River, Christian Co. near Boaz, MO.	400	160	172	60	5	11	2	13	14
Finley Creek, Christian Co.	306	140	152	50	7	4	2	6	6
Current River, Ripley Co.	285	148	150	30	18	2	1	4	2
Fourche River, Randolph Co.	401	218	222	45	27	2	1	6	2
Spring River, Oregon Co.	435	226	238	50	27	2	1	7	2
Eleven Point River, Oregon Co.	328	168	177	37	20	2	1	4	2
Spring River, Jasper Co.	262	103	122	44	3	5	2	14	6
Center Creek, Jasper Co. near Carterville, MO.	307	113	133	44	2	5	1	15	7
Center Creek, Jasper Co. near Smithville, MO.	353	107	163	61	3	6	2	44	6
Lost Creek, Newton Co.	229	100	109	41	1	3	1	7	4
Elk River, McDonald Co.	258	118	126	46	2	3	1	6	4
Buffalo Creek, McDonald Co.	253	109	117	45	1	4	2	8	5
Current River, Shannon Co.	251	120	126	27	15	2	1	7	3

	SC	Alk	Hard	Ca	Mg	Na	K	SO_4	Cl
Jacks Fork River, Shannon Co.	317	161	162	33	20	1	1	4	2
Mean	316	143	156	42	12	4	1	11	5
Southeastern Lowlands									
Headwater Diversion, Cape Girardeau Co.	209	94	101	23	11	3	1	8	3
St. Francis River, Clay Co. AK	167	71	77	17	8	3	2	11	3
Black River, Butler Co.	197	95	104	22	11	3	1	8	3
Little Black River, Ripley Co.	202	96	102	21	12	2	1	5	2
Mean	194	89	96	21	10	3	1	8	3

[a] 1974 yearly averages (U.S.G.S., 1974)

Table 6. Results of t-tests of mean water chemistry values measured in rivers within the Dissected Till Plains, the Ozark Uplands, and the Southeastern Lowlands.[a]

	Comparisons of:	
Parameter	Southeastern Lowlands vs Dissected Till Plains Ozark Uplands	Dissected Till Plains vs Ozark Uplands
Specific conductance micromhos/cm at 25 C	X	
Total alkalinity as mg/l $CaCO_3$	X	
Total hardness as mg/l $CaCO_3$	X	
Calcium mg/l	X	
Magnesium mg/l		
Sodium mg/l	X	X
Potassium mg/l	X	X
Sulfate mg/l	X	X
Chloride mg/l		X

[a] X indicates significant difference at P = 0.01

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