WATER QUALITY ASSESSMENT IN THE GALLINAS WATERSHED, LAS VEGAS, NEW MEXICO

RESEARCH AND REPORT WRITTEN BY:

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TABLES AND FIGURES

ABSTRACT

This research was conducted to evaluate water quality conditions within the Gallinas Watershed. The Gallinas River originates in Precambrian crystalline rocks of the southern Sangre de Cristo Mountains and flows southeast toward Paleozoic and Mesozoic strata of the Las Vegas basin. The Gallinas River is the primary source of water for Las Vegas, NM, providing 95% of its domestic water supply. Additional surface water is diverted to the Storrie Lake Water Project and divided among multiple users, including the Las Vegas National Wildlife Refuge, farmers, and ranchers.

Seven surface water samples were collected from the Gallinas River beginning in the upper headwaters and ending downstream of the Las Vegas wastewater treatment plant. Additional surface water samples were collected from Storrie and McCallister Lakes, two Storrie Lake Water Project diversions. Representative indicator parameters Ca, Na, Cl, and SO_4 increase from 11.8-142, 4.5-92.3, 1.3-62.2, and 9.9-450 mg/L respectively from the headwaters to the lower river sites. Likewise, hardness, alkalinity, conductivity, and total dissolved solids are appreciably higher in the lower Gallinas River. These results demonstrate a correlation between water quality degradation and percentage of exposed sedimentary rocks with which the Gallinas River comes into contact.

An interesting observation is the dramatic degradation in water quality at McCallister Lake, the largest surface water body at the Las Vegas National Wildlife Refuge. Data show elevated concentrations of Ca (402), Na (1165), Cl (678), SO4 (3525) (mg/L) and conductivity (11,200 micromohs/cm). Thenardite precipitates along the shoreline during the summer and fall indicating that localized zones of saturation for Na and SO_4 exist seasonally within the shallow lake. Ground water samples collected from seeps along the Gallinas River canyon and down gradient of McCallister Lake show all indicator parameters occur at concentrations intermediate between those of McCallister Lake and local domestic wells. These data suggest that water within the seeps is the blending of surface water that infiltrates from the lake and mixes with ground water before discharging to the lower Gallinas River. Further study of evaporation effects as well as

anthropogenic and natural aquifer contributions to water quality is warranted to improve water management practices within the Gallinas Watershed.

INTRODUCTION

Gallinas River is a tributary of the Pecos River Stream System in northern New Mexico that yields an average of 3,100 acre-feet of water annually (Montoya 2000). The Gallinas River originates in the southern Sangre de Cristo Mountains and flows southeast towards the high plains desert community of Las Vegas. A large percentage of flow is diverted to the Storrie Lake Water Project and divided among multiple users, including the city of Las Vegas, Las Vegas National Wildlife Refuge, farmers and ranchers. Continuing and growing demands for water necessitate that the Gallinas River be managed for water production and protection of water quality.

Garn and Jacobi (1996) presented baseline water quality data for the Gallinas River and related water quality characteristics to spatial differences in the geology of the watershed. We aimed to expand upon their study and examine the spatial changes in water quality throughout a greater portion of the watershed. We wanted to look particularly at the impacts of water quality within the Storrie Lake Water Project diverted water system. We collected seven surface water samples from the Gallinas River starting at the upper headwaters and ending downstream of the Las Vegas wastewater treatment plant (Figs. 1, 2). Additional surface water samples were collected from Storrie and McCallister Lakes, two Storrie Lake Water Project diversions. Ground water samples were collected from natural springs along lower Gallinas canyon and a local domestic well. All water samples were analyzed for dissolved minerals, salts, metals, cations and anions. The results were plotted on histograms and radial plots to assess water quality changes throughout the watershed.

PROJECT GOALS

The general objective of this study was to examine the spatial changes in water quality throughout the Gallinas Watershed. The specific project goals include:

- Collect baseline surface water and ground water data within the Gallinas watershed.

- Evaluate changes in water quality from the upper mountain headwaters to downstream urban center (Las Vegas) and diversion points (Storrie Lake Water Project).
- Assess natural contributions to spatial variability in water quality.
- Evaluate changes in water quality along a ground water flow path that originates within surface locations at the Las Vegas National Wildlife Refuge (McCallister Lake) and extends through a shallow bedrock aquifer before discharging as seeps along lower Gallinas Canyon.

STUDY AREA

Gallinas Watershed

The Gallinas Watershed is located between the Canadian River Watershed to the east and the Rio Grande Watershed to the west and covers an area of 52,500 acres. The Gallinas River originates at an elevation of 11,661 feet at Elk Mountain on the eastern flanks of the Sangre de Cristo Mountains. The stream flows to the southeast through the city of Las Vegas before merging with the Pecos River.

Land ownership within the Gallinas watershed is subdivided among private (21%), federal (62%), and state/county entities (17%) (Montoya, 2000). The land is primarily designated as federal forest land (62%) and supports recreation, wetlands, wildlife habitat and timber harvesting. The remaining watershed land area supports municipal, domestic, and irrigation supplies. Gallinas River is the primary water supply for the City of Las Vegas, New Mexico (population 16,000).

Geology

The study area is situated on the Great Plains where the prairie meets the Rocky Mountains. The region consists of native grasslands, farm and ranch lands, marshes, ponds, timbered canyons and streams. The region is primarily underlain by Cretaceous age (~65-145 million year old) rock formations and Tertiary age (~65 million year old to present) alluvium and gravel deposits (Fig. 3). The Cretaceous Dakota Group, Graneros Shale, Greenhorn Limestone, Carlile Shale and Niabrora Shale uncomformably overlie

Paleozoic sedimentary strata and Precambrian crystalline rocks. The Paleozoic and Cretaceous strata strike due north through the Las Vegas area and are steeply dipping and overturned to the west (Baltz, 1972) (Fig. 3). The units fold at depth into an asymmetrical syncline that defines the Las Vegas sub basin of the Raton sedimentary basin. East of Las Vegas, the stratigraphic units lie horizontally. The following rock descriptions, from oldest to youngest, are summarized from Lessard and Bejnar (1976).

Dakota Group The Dakota Group is divided into the Lower Sandstone Unit, Middle Shale Unit, and the Upper Sandstone Unit. The Lower Sandstone Unit is a cross-stratified quartz arenite. It is coarse- to fine-grained and ranges in color from a grayish-orange to a light gray. The Middle Shale Unit comprises silty, quartz arenite combined with black carbonaceous shale. The Upper Sandstone Unit is a fine- to medium-grained, pale colored well-cemented highly resistant quartz arenite. It is tilted on end in the central portion of the study area and defines the north-striking Creston Ridge. The Dakota Group is approximately 36.9 m thick and outcrops along the highest levels of Gallinas Canyon.

Graneros Shale and Greenhorn Limestone The Graneros Shale is 68.6 m thick. It is comprised of alternating fine sandstone, siltstones, and shales. The Graneros Shale is easily weathered and typically outcrops as a valley fill. The unit forms a gradational contact with the Greenhorn Limestone, a light gray colored unit that consists of interbedded limestone and calcareous shale. The Greenhorn Limestone underlies the drainages within the lower Gallinas canyon and is the predominant source of ground water seepage in the study area.

Carlile Shale The Carlile Shale is an approximately 67.0 m thick dark gray shale unit that consists of yellow-brown cross-laminated arenite that contains shallow water fossils.

Niobrara Formation The Niobrara Formation is 185.0 m thick and includes dark colored shales and fine-grained siltstones interbedded with thin layers of limestone. This unit outcrops around Storrie Lake and contains abundant freshwater fossils including shark teeth, ray teeth, ammanoid shell impressions and various shelly fauna.

RESEARCH METHODS

Surface water and ground water samples were collected in prewashed Nalgene bottles. The bottles were filled to the rim with water, capped, and placed on ice. The water samples were delivered to Albuchemist Laboratories, Albuquerque, New Mexico, for multiple mineral analyses as well as pH, conductivity, and total dissolved solids measurements. Duplicate samples were collected at each site for hardness and alkalinity tests at New Mexico Highlands University laboratories. Table 1 is a list of the parameters that were measured, with reference to the analytical methods used.

Hardness and Alkalinity

Hardness and alkalinity tests were conducted at New Mexico Highlands University laboratories by Evans. The formulas and the procedures for measuring each were taken from *Standard Methods for the Examination of Water and Wastewater*, 20th edition (1998). Hardness tests determine the amount of calcium and magnesium salts in water. Standard titration methods were employed using 25 milliliters (mL) of sample. Hardness values were calculated using the following formula:

Hardness (mg CaCO3/L) = A x B x 1,000/mL sample

where A = mL titration for sample and

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant.

Note:

B = 1.50 mg $CaCO_3$ for 0.015 M EDTA (Trial 1) and

B = 0.98 mg $CaCO_3$ for 0.015 M EDTA (Trial 2).

Alkalinity is the total concentration of bases in water and the ability of water to neutralize acids. Standard titration methods were employed utilizing 100 mL of sample. Alkalinity values were calculated using the following formula:

Alkalinity (mg CaCO3/L)		=	A x N x 50,000/mL sample
where	A	=	mL standard acid used and
	N	=	normality of standard acid (0.02 M).

RESULTS

All water chemistry results are listed in Tables 2 and 3 and shown on Figs. 4-8. A summary of the results follows.

Calcium, Magnesium, and Sodium

Major cation concentrations show a general increase in a downstream direction throughout the watershed. Calcium (Ca), magnesium (Mg), and sodium (Na) increase from 11.8-142, 2.0-33.3 and 45.0-92.3 mg/L respectively from the headwaters to the lower river sites. Gallinas Canyon ground water seeps show high values of Ca (209 mg/L), moderate values of Mg (51.2 mg/L) and moderate values of Na (148 mg/L). Storrie Lake had moderate cation concentrations (Ca 92.4 mg/L, Mg 19.9 mg/L, and Na 44.0 mg/L). The Montezuma Hot Springs had high Na concentration (190 mg/L). Storrie Lake had the highest major cation concentrations (Ca 402.0 mg/L, Mg 365.5 mg/L, and Na 1188 mg/L).

Iron

All surface water and ground water samples contained less than 1.0 mg/L of iron (Fe) and were within the drinking water safety limits of 0.3 mg/L concentration (Brooks, Folliott, Gregersen, & DeBano, 1997). Ground water Fe values were typically below the laboratory detection limits (<0.05 mg/L). Storrie Lake had higher Fe values than McCallister Lake (0.63 and 0.09 mg/L respectively).

Chloride

Chloride (Cl) concentrations show a general increase in a downstream direction throughout the watershed. Cl increased from 1.3 to 68.8 mg/L from the Upper Gallinas River to the Lower Gallinas River sampling sites. The Gallinas Canyon ground water seeps showed an average Cl concentration of 111 mg/L. Storrie Lake showed relatively low Cl concentrations (13.9 mg/L) while McCallister Lake had the highest Cl concentrations (693 mg/L).

Sulfate

Sulfate (SO_4) values increased from the Upper Gallinas River (9.9 mg/L) downstream to San Augustine (450 mg/L). Ground water discharging from Gallinas Canyon seeps showed high SO_4 concentrations (average 628 mg/L). Storrie Lake had moderate SO_4 concentrations (206 mg/L) while McCallister Lake had extremely high SO_4 concentrations (3585 mg/L).

Bicarbonate

Bicarbonate (HCO_3) values increased throughout the watershed from the Upper Gallinas River (44.5 mg/L) downstream to St. Augustine (214 mg/L). Ground water draws along the canyon showed high HCO_3 values, averaging 266 mg/L. Storrie Lake and McCallister Lake had moderate HCO_3 values (150.25 and 113 mg/L respectively).

Nitrate

Most nitrate nitrogen (as N) values throughout the study area were very low (< 1.0 N mg/L). Nitrate showed a general increase in a downstream direction throughout the watershed from 0.11 N at the Upper Gallinas River site to 6.91 at the Lower Gallinas River site. Note that these values are below the New Mexico Water Quality Standards of < 10.0 mg/L (New Mexico Water Quality Control Commission, 1991).

Hardness

Water hardness is described qualitatively using the following scale: soft water, 0-60 mg/L; moderately hard, 61-120 mg/L; hard, 121-180 mg/L; very hard, more than 180 mg/L (Brooks and others, 1997). Surface water samples increased in hardness from the Upper Gallinas to Lower Gallinas River sites. Surface water from the Hermit's Peak Trailhead (37.7 mg $CaCO_3$/L) and Hot Springs (6.4 mg $CaCO_3$/L) were soft, while water from the Skating Pond to the St. Augustine increased from 85.7 to 487 mg $CaCO_3$/L.

Ground water samples from the Gallinas Canyon seeps were very hard, averaging 733 mg $CaCO_3$/L. Storrie Lake and McCallister Lake were also very hard, with hardness values of 282 and 2495 $CaCO_3$/L respectively.

Alkalinity

Waters in the study area had alkalinity values ranging from 36.7 to 227 $CaCO_3$. Alkalinity increased throughout the watershed from the Upper Gallinas (36.7 $CaCO_3$) to Lower Gallinas River (185 $CaCO_3$) sites. Alkalinity was highest in the ground water discharging from the canyon seeps, averaging 221 $CaCO_3$. Storrie Lake (127 $CaCO_3$) and McCallister Lake (121 $CaCO_3$) had moderate alkalinity values.

pH

All of the water samples were slightly alkaline, having pH values between 7.35 and 8.37.

Conductivity and Total Dissolved Solids

Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current. The higher the concentration of total dissolved solids (TDS) in a water sample, the higher its conductivity. Conductivity and TDS are strongly correlated throughout the study area ($R^2 = 0.9975$) (Fig. 9). Conductivity and TDS increase in a downstream direction throughout the watershed (110 to 1610 micromohs/cm and 76 to 1018 mg/L respectively). Storrie Lake shows moderate to high conductivity (975 micromohs/cm) and TDS (513 mg/L) while McCallister Lake shows extremely high conductivity (11000 micromohs/cm) and TDS (7313 mg/L).

DISCUSSION

The composition of stream water often reflects the composition of the drainage-basin geology with which the water has been in contact. Major cations (Ca, Mg, Na), anions (Cl and SO_4), and other indicator parameters increase in the Gallinas River in a downstream direction illustrating the differences in geology in the watershed. Water quality shows little change over an approximately 20 kilometer stretch from the Upper Gallinas Source to the Montezuma Skating Pond. Throughout this reach, the river flows over Precambrian crystalline rocks (granites, granitic gneisses, amphibolites and schists) which contain silicate minerals having low solubilities and slow responses to weathering. Water quality degrades markedly in terms of dissolved NaCl and $CaSO_4$ and other water parameters from the Montezuma Pond to the Lower Gallinas River sampling sites over an approximately 40 kilometer stretch. Along this expanse, the river flows over Cretaceous limestones and limey shales of the Niabrora, Carlile, Greenhorn and Graneros formations. The sedimentary rocks are more permeable than the crystalline rocks of the upper watershed and contain major amounts of highly soluble calcite ($CaCO_3$) and minor amounts of gypsum ($CaSO_4$). Some of the elevated NaCl concentrations are attributed to the Montezuma Hotsprings, which issue Na- and Cl- rich waters to the river.

Storrie Lake and McAllister Lake exhibit extremely high concentrations of dissolved Na, Cl, Ca, and SO_4 compared to other surface water and ground water samples throughout the watershed. We ascribe these high salt concentrations to evaporation effects. As the lake levels lower during low precipitation periods (summer and winter), the bedrock is exposed. Calcium, magnesium, and sodium salts are leached from the limestones and lime-rich shales underlying the region. With continuous evaporation, soils become dry and salt efflorescence occurs (NDSP, 2004), explaining the presence of thenardite on Melton Pond (Evans and Lindline, 2003). Subsequent precipitation events can cause runoff that is rich in dissolved salts to enter the lake. While Storrie Lake shows high concentrations of dissolved minerals, the concentrations were much lower than at McCallister Lake. There is apparently a larger flux of water through Storrie Lake from small stream drainages and landscape runoff than to McCallister Lake. This large flux of fresh water dilutes the dissolved mineral concentration at Storrie Lake. McCallister Lake, however, relies solely on allotments of water from the Storrie Lake Water Project. The water contributions to the system are not sufficient to balance evaporation effects. The high salt concentrations in McCallister Lake have serious implications regarding the health and stability of the Las Vegas National Wildlife Refuge. The refuge hosts over ten lakes ranging from 0.10 to 1.10 kilometers in diameter that provide habitat for a wide variety of plants, migratory birds and other wildlife. Increasing salt concentrations in the lakes and soils limit nutrient uptake by biota. Saline conditions place environmental stress on riparian flaura and fauna and threaten the vitality of the refuge lake ecosystem.

Cations, anions and other water parameters are relatively higher in Gallinas Canyon ground water seeps than most surface water samples. We attribute the high chemical load in the seeps to dissolved loading in the subsurface. Infiltrated water enters the subsurface as storage through primary matrix porosity, but is transmitted through vertical fractures, joints, and bedding plane separations. Groundwater has a longer residence time in contact with bedrock and thus the potential to dissolve minerals during transit. That water subsequently gets released from storage, migrates through fractures, and discharges along seepage faces of Gallinas Canyon.

We explored the possibility that water that drains from McCallister Lake into the subsurface contributes to chemical loading of ground water. We collected a ground water sample from a local domestic well (Charles R. Ranch) and compared its chemistry to the chemistry of McCallister Lake and the Gallinas Canyon seeps (Table 4). The local ground water shows lower Na, Ca, Cl, and SO_4 concentrations than the ground water seeps. We applied a least squares mixing model to calculate the composition of a solution resulting from mixing various proportions of McCallister Lake water and Charles R. Ranch ground water. Our results indicate that the ground water seeps have an average composition approaching a blend of 14% McCallister Lake water and 86% ground water (Table 4). These results suggest that infiltration from McCallister Lake is relatively minor contributor to chemical loading to the lower Gallinas River.

CONCLUSION

As hypothesized, the water chemistry throughout the Gallinas Watershed is degrading from the river's headwaters to lower river sites probably due to difference in the geology in the watershed. From the Upper Gallinas River site to the Montezuma Pond, the river drains predominantly from low permeable, weathering resistant crystalline rocks. For the remainder of the watershed studied, the river drains highly permeable calcite- and gypsum-bearing sedimentary rock formations which contribute Ca, SO_4, HCO_3 and other chemical species to surface and ground water supplies. Well log data are necessary to understand the contribution of individual hydrostratigraphic units to chemical loading within the watershed.

Ground water seeps discharging along the Gallinas River canyon have chemical signatures approaching a mixture of 14% surface water (McCallister Lake) and 86% ground water (local domestic well). Mixing calculations indicate that vertical leakage from McCallister Lake is a relatively minor contributor to ground water recharge and subsequently, chemical loading to the Lower Gallinas River.

Of note are the elevated Ca, Na, Cl, SO_4 concentrations and conductivity and TDS measurements at McCallister Lake. These data suggest that high evaporation rates relative to water input rates are enriching dissolved salt concentrations at McCallister Lake and other surface water reservoirs at the Las Vegas National Wildlife Refuge. Continued drought conditions will enhance evaporation rates at the refuge and lead to increasing accumulation of dissolved salts and minerals, potentially threatening the vitality of the refuge ecosystem. As saline soils place an environmental stress on riparian flaura and fauna, surface water conveyance operations at the Las Vegas National Wildlife Refuge need to be optimized to reduce evaporation effects at McCallister Lake. A comprehensive water and chemical budget analysis is needed to examine the factors influencing water quality and improve management practices at the refuge. With a limited water supply, the city of Las Vegas, Storrie Lake Water Project, and other Gallinas River users face issues concerning the conservation of its most potable resource.

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Table 1. Parameters measured for water analyses and analytical methods used. The analytical methods listed refer to page numbers in the *Standard Methods for the Examination of Water & Wastewater*, 18th edition (1992).

PARAMETER	ANALYTICAL METHODS*
Calcium	3111.B
Magnesium	3111.B
Sodium	3500-NaD
Iron	3111.B
Hardness (as $CaCO_3$)	2340.B
Sulfate	4500-SO4E
Chloride	4500-Cl D
Carbonate	2320.B
Bicarbonate	2320.B
Alkalinity (as $CaCO_3$)	2320.B
pH	4500-H B
Conductivity (micromhos/cm)	2510.B
Total dissolved solids	2540.B
Nitrate (as N)	4500-NO3. E
Fluroide	4500-F. D
Silica	4500-Si D

Table 2. Hardness and Alkalinity data comparing results from Albuchemist and New Mexico Highlands University laboratories.

HARDNESS					
Site	Albuchemist	NMHU (Avg)	AVERAGE	ST DEV	PRECISION %
Lower Gallinas	453	494	473.5	29.0	6.1
Gallinas Canyon Seep 1	763	800	781.5	26.2	3.3
Gallinas Canyon Seep 2	704	708	706.0	2.8	0.4
Gallinas Canyon Seep 3	723	755	739.0	22.6	3.1
Gallinas Canyon Seep 4	740	722	731.0	12.7	1.7
McCallister Lake	2535	2286	2410.5	176.1	7.3
Storrie Lake	330	330	329.9	0.1	0.0

ALKALINITY					
Site	Albuchemist	NMHU (Avg)	AVERAGE	ST DEV	PRECISION %
Lower Gallinas	160	166	163.0	4.2	2.6
Gallinas Canyon Seep 1	214	200	206.8	10.3	5.0
Gallinas Canyon Seep 2	222	212	216.8	7.4	3.4
Gallinas Canyon Seep 3	222	219	220.5	2.1	1.0
Gallinas Canyon Seep 4	227	226	226.5	0.7	0.3
McCallister Lake	99	90	94.3	6.1	6.4
Storrie Lake	140	134	136.8	3.9	2.8

Table 3. Water chemistry analytical results. Site descriptions correspond to tags on site map (Figs. 1 and 4).

SAMPLE / SITE	DESCRIPTION	Ca	Mg	Na	Si	Fe	Cl
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TE03-27/S16	Hermits Peak Trailhead	11.8	2	4.5	11.4	0.19	1.3
TE03-28/S17	Skating Pond	30.4	2.4	6.3	4.0	<0.05	2.5
TE03-30/S18	Hot Springs	3.9	<0.5	190	18.4	<0.05	151
TE0-33/S19	Middle Gallinas River 1	56.4	7.12	37.5	10.8	0.13	32.5
TE0-34, 35/S20 (avg)	Middle Gallinas River 2	105	27.1	54.7	5.5	<0.05	0.83
TE03-1/S1	Lower Gallinas River	131	30.7	92.3	3.2	0.17	62.2
TE0-36, 37/S21 (avg)	St Augustin	142.5	33.3	78	1.8	<0.05	68.8
TE03-3/S2	Gallinas Canyon Seep 1	212	56.8	142	12.1	<0.05	125
TE03-12/S9	Gallinas Canyon Seep 2	207	45.4	154	13.4	<0.05	102
TE03-14/S10	Gallinas Canyon Seep 3	205	51.4	140	23.3	0.09	108
TE03-16/S11	Gallinas Canyon Seep 4	212	51.1	155	9.2	<0.05	109
TE03-18, 22/S12 (avg)	McCallister Lake (Nov03)	402	371.5	1165	3.6	0.09	678
TE03-38, 39/S12 (avg)	McCallister Lake (March04)	384.5	357.5	1210	0.3	-----	709
	McCallister Lake (avg)	393.3	364.5	1188	1.9	0.09	693
TE03-20, 23/S13 (avg)	Storrie Lake (Nov 03)	92.4	24.2	42.5	11.1	0.63	13.1
TE03-40, 41/S13 (avg)	Storrie Lake (March04)	67.6	15.6	45.5	0.4	-----	14.6
	Storrie Lake (avg)	80.0	19.9	44.0	5.7	0.63	13.9

SAMPLE / SITE	DESCRIPTION	F	SO4	CaCO3	Bicarbonate	Nitrate	Hardness
		mg/L	mg/L	mg/L	mg/L	as N	as CaCO3
TE03-27/S16	Hermits Peak Trailhead	0.52	9.9	<1.0	44.5	0.11	37.7
TE03-28/S17	Skating Pond	0.43	13.3	2.1	121	0.11	85.7
TE03-30/S18	Hot Springs	26.7	38.5	1.4	117	0.04	6.4
TE0-33/S19	Middle Gallinas River 1	2.69	66.4	3.3	159	0.04	170
TE0-34, 35/S20 (avg)	Middle Gallinas River 2	64.8	286	1.0	171	0.05	309
TE03-1/S1	Lower Gallinas River	0.86	348	<1	195	6.91	453
TE0-36, 37/S21 (avg)	St Augustin	0.78	450	6.0	214	2.18	487
TE03-3/S2	Gallinas Canyon Seep 1	0.95	660	3.3	258	0.22	763
TE03-12/S9	Gallinas Canyon Seep 2	0.95	603	2.5	267	0.96	704
TE03-14/S10	Gallinas Canyon Seep 3	0.92	630	2.3	267	0.71	723
TE03-16/S11	Gallinas Canyon Seep 4	0.94	619	3.5	272	0.50	740
TE03-18, 22/S12 (avg)	McCallister Lake (Nov03)	3.38	3525	60.0	59	0.04	2535
TE03-38, 39/S12 (avg)	McCallister Lake (March04)	2.99	3645	4.3	167	0.06	2455
	McCallister Lake (avg)	3.18	3585	32.2	113	0.05	2495
TE03-20, 23/S13 (avg)	Storrie Lake (Nov 03)	1.14	190	2.4	168	0.06	330
TE03-40, 41/S13 (avg)	Storrie Lake (March04)	1.06	223	4.0	133	0.08	233
	Storrie Lake (avg)	1.10	206	3.2	150	0.07	282

Table 3. Water chemistry analytical results continued.

SAMPLE / SITE	DESCRIPTION	Alkalinity	pH	Conductivity	TDS	T ANIONS	T CATIONS
		as CaCO3	mg/L	micromhos/cm	mg/L		
TE03-27/S16	Hermits Peak Trailhead	36.7	7.4	110	76	1.00	0.97
TE03-28/S17	Skating Pond	103	8.5	230	108	2.35	1.97
TE03-30/S18	Hot Springs	100	8.2	1050	492	8.41	8.46
TE0-33/S19	Middle Gallinas River 1	135	8.4	595	332	5.05	5.04
TE0-34, 35/S20 (avg)	Middle Gallinas River 2	141	7.9	1265	784	12.19	9.85
TE03-1/S1	Lower Gallinas River	160	7.4	1380	780	12.35	13.08
TE0-36, 37/S21 (avg)	St Augustin	185	8.4	1610	1018	16.56	13.24
TE03-3/S2	Gallinas Canyon Seep 1	214	8.1	2800	1440	21.55	21.43
TE03-12/S9	Gallinas Canyon Seep 2	222	8.0	2200	1256	19.87	20.76
TE03-14/S10	Gallinas Canyon Seep 3	222	8.0	2400	1348	20.60	20.55
TE03-16/S11	Gallinas Canyon Seep 4	227	8.0	2600	1352	20.48	21.53
TE03-18, 22/S12 (avg)	McCallister Lake (Nov03)	99	8.1	11200	7060	93.65	101.30
TE03-38, 39/S12 (avg)	McCallister Lake (March04)	143	8.2	10800	7566	98.79	101.23
	McCallister Lake (avg)	121	8.1	11000	7313	96.22	101.27
TE03-20, 23/S13 (avg)	Storrie Lake (Nov 03)	140	8.1	1030	504	7.13	8.47
TE03-40, 41/S13 (avg)	Storrie Lake (March04)	115	8.2	920	522	7.28	6.63
	Storrie Lake (avg)	127	8.1	975	513	7.21	7.55

SAMPLE / SITE	DESCRIPTION	NaCl	CaSO4	SiO2	CaCO3	CaMg(CO3)2
		mg/L	mg/L	mg/L	mg/L	mg/L
TE03-27/S16	Hermits Peak Trailhead	2.1	14.0	8.45	11.42	15.15
TE03-28/S17	Skating Pond	4.1	18.4	3.07	51.50	18.18
TE03-30/S18	Hot Springs	249	55.3	13.83	-----	-----
TE0-33/S19	Middle Gallinas River 1	54.5	93.6	8.45	41.85	53.77
TE0-34, 35/S20 (avg)	Middle Gallinas River 2	1.4	406	4.23	-----	-----
TE03-1/S1	Lower Gallinas River	103	493	2.46	-----	-----
TE0-36, 37/S21 (avg)	St Augustin	1.3	638	1.38	-----	-----
TE03-3/S2	Gallinas Canyon Seep 1	206	936	9.30	-----	-----
TE03-12/S9	Gallinas Canyon Seep 2	168	855	10.30	-----	-----
TE03-14/S10	Gallinas Canyon Seep 3	178	893	17.90	-----	-----
TE03-16/S11	Gallinas Canyon Seep 4	180	878	7.07	-----	-----
TE03-18, 22/S12 (avg)	McCallister Lake (Nov03)	1118	4998	2.73	-----	-----
TE03-38, 39/S12 (avg)	McCallister Lake (March04)	1170	5168	0.27	-----	-----
	McCallister Lake (avg)	1144	5083	1.50	-----	-----
TE03-20, 23/S13 (avg)	Storrie Lake (Nov 03)	21.6	269	8.53	-----	-----
TE03-40, 41/S13 (avg)	Storrie Lake (March04)	24.1	315	0.28	-----	-----
	Storrie Lake (avg)	22.9	292	4.40	-----	-----

Table 4. Results from step-wise mixing of McCallister Lake (Solution 1) and Charles R. Ranch well water (Solution 2). Mixing of 14% lake sample water with 86% well water sample yields a mixture that closely matches average Gallinas Canyon seep water.

		NA	CA	CL	SO4
		(mg / L)	(mg / L)	(mg / L)	(mg / L)
Solution 1	McCallister Lake	1165.0	402.0	678.0	3525.0
Solution 2	CRR Well	38.0	76.1	28.9	98.0
Optimized Sample	Gallinas Canyon Seeps (avg)	147.8	209.0	111.0	628.0
Mixing Results	14% Sol 1; 86% Sol 2	195.8	121.7	119.7	577.8
Percent Difference (calculated versus measured)		24.5	71.7	7.3	8.7

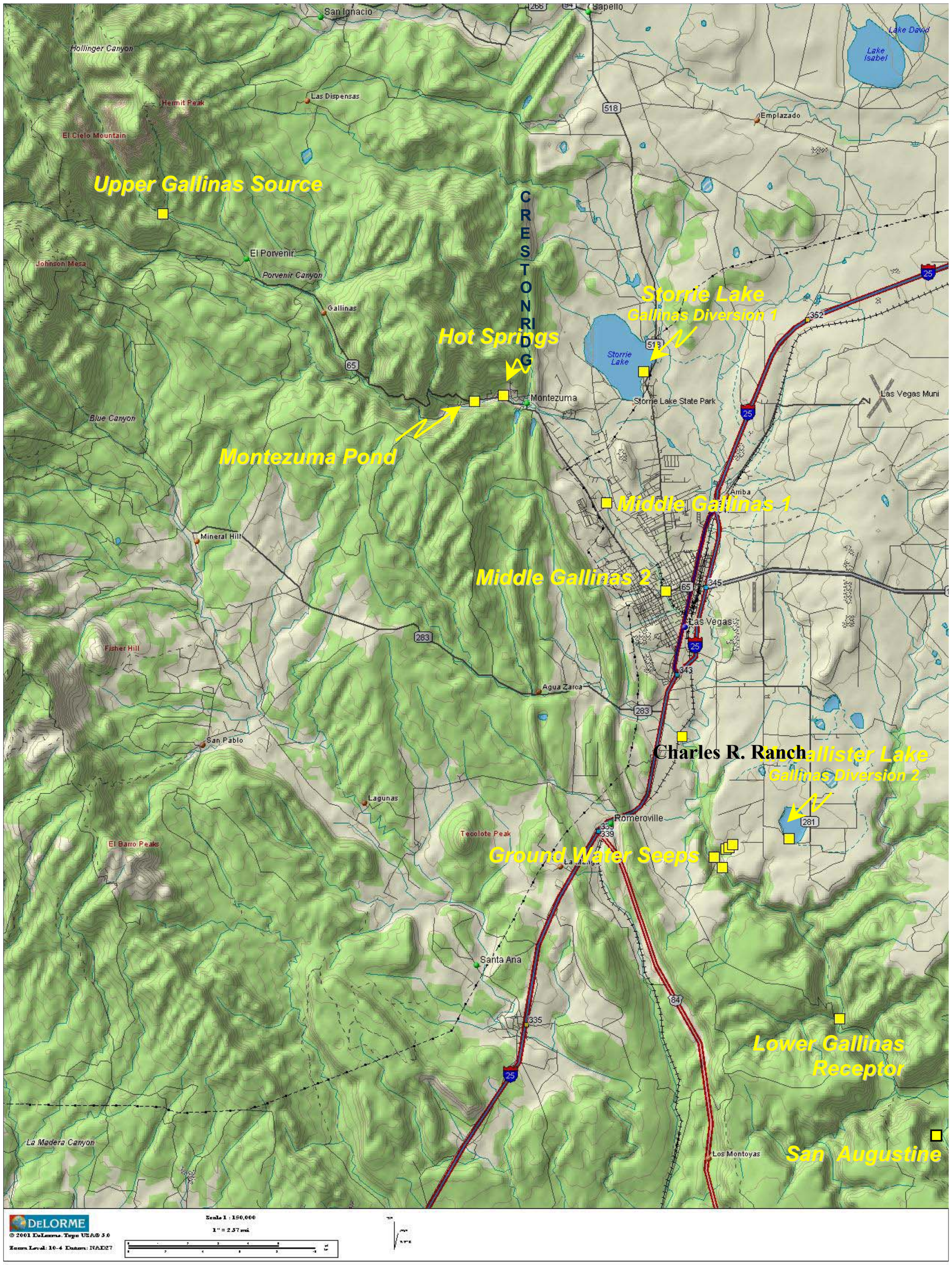
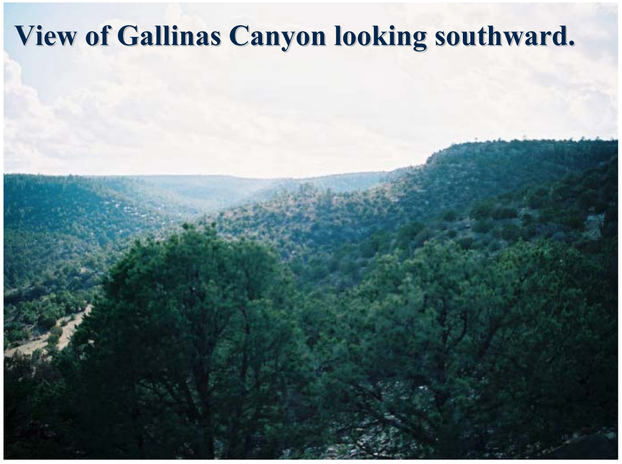
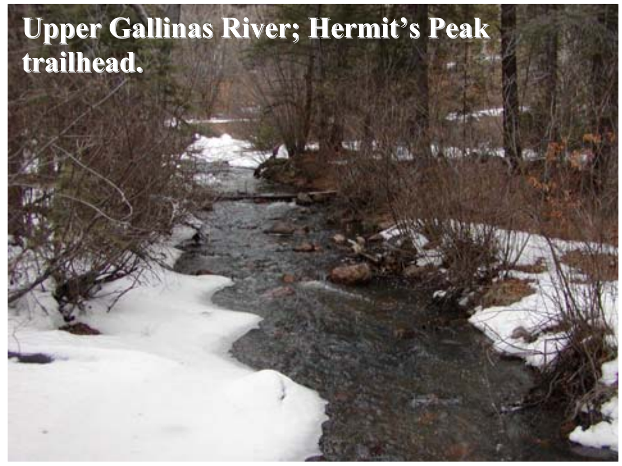


Figure 1. Topographic map of the region showing water sampling localities.



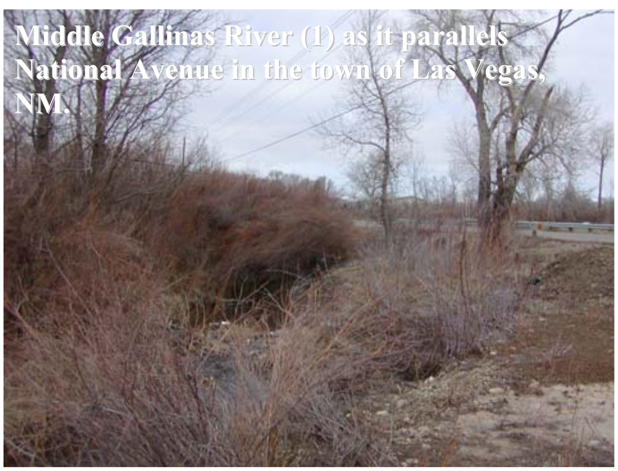
View of Gallinas Canyon looking southward.



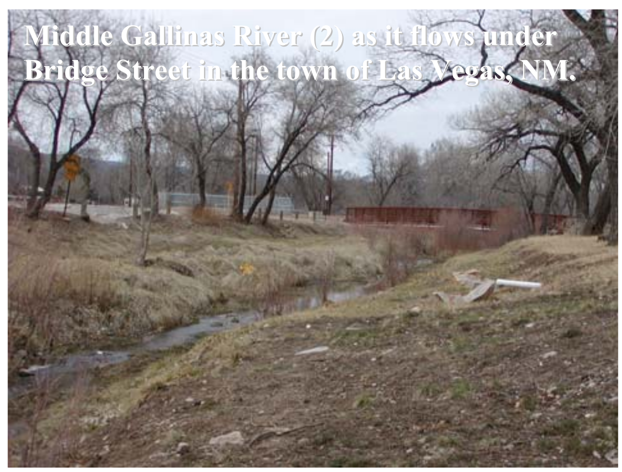
Upper Gallinas River; Hermit's Peak trailhead.

Montezuma pond.

Montezuma hot springs. Gallinas River flows through center of photograph.



Middle Gallinas River (1) as it parallels National Avenue in the town of Las Vegas, NM.



Middle Gallinas River (2) as it flows under Bridge Street in the town of Las Vegas, NM.

Figure 2. Photographs of the region and sampling locations.

AGE	LITHOLOGIC UNITS	THICKNESS
CRETACEOUS	NIOBRARA FM. –	
	SMOKY HILL MARL MBR.	900'
	FT. HAYS LS. MBR.	0-55'
	BENTON FM.	
	CARLILE SH.	165-225'
	GREENHORN LS.	20-70'
	GRANEROS SH.	175-400'
	DAKOTA SS.	140-200'
	PURGATOIRE FM. – SS. & SH.	100-150'
JURASSIC	MORRISON FM.	150-400'
	WANAKAH FM.	30-100'
	ENTRADA SS.	40-100'
TRIASSIC	DOCKUM GROUP – SH'S & SS'S	0-1200'
PERMIAN	BERNAL FM.	0-125'
	SAN ANDRES LS.	10-20'
	GLORIETA SS.	50-200'
	YESO FM.	200-400'
?	SANGRE DE CRISTO FM.	700-5300'
PENNSYLVANIAN	MAGDALENA GRP. – LS'S., SH. & SS.	4000-5000'
MISSISSIPPIAN	TERERRO FM. – LS'S.	40-50'
DEVONIAN ?	ESPIRITU SANTO FM. – DOL. LS.	25'
PRE-CAMBRIAN	MAFIC GNEISS GRP.	7000' ?
	METAQUARTZITE GRP.	5000' ?
	GRANITE & GRANITE GNEISS	4000'?

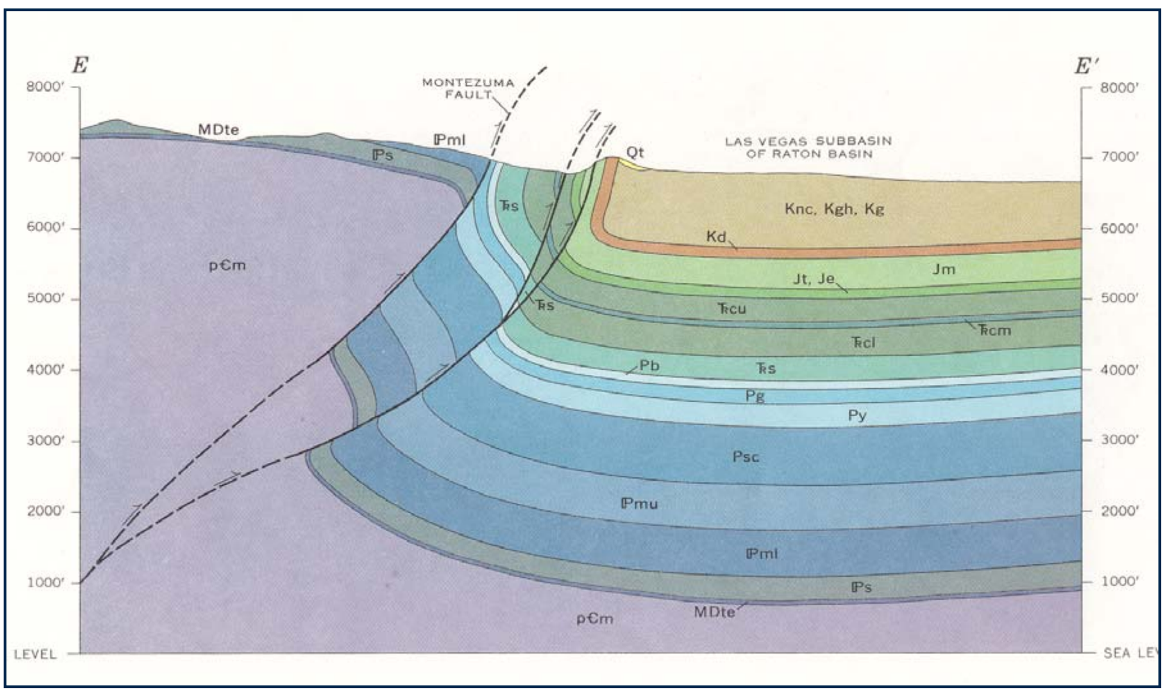


Figure 3. Upper: Abbreviated stratigraphic column denoting the units that outcrop throughout the study area (Lessard and Bejnar, 1976). Lower: Cross-section showing the major rock types that make up the subsurface geology and their structural form (Baltz, 1972).

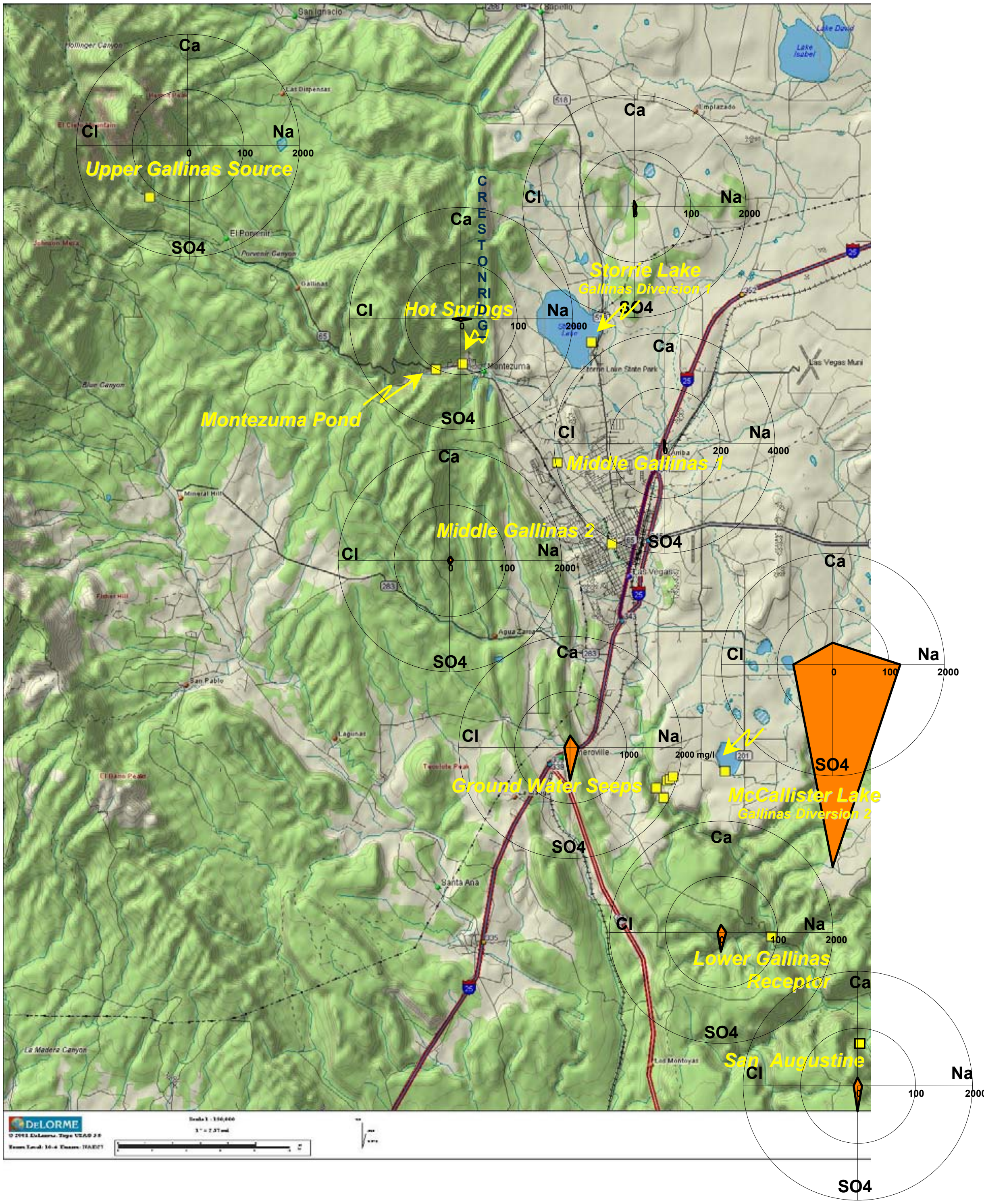


Figure 4. Radial plots comparing the relative concentrations of Ca-Cl-SO_4-Na (mg/L) in sampled waters. Major cation and anion concentrations increase from the Upper Gallinas Source to the lower Gallinas River Receptor and San Augustine, shown by the size of the orange-shaded polygons. The very large polygon at McCallister Lake demonstrates the lake's large cation-anion concentrations.

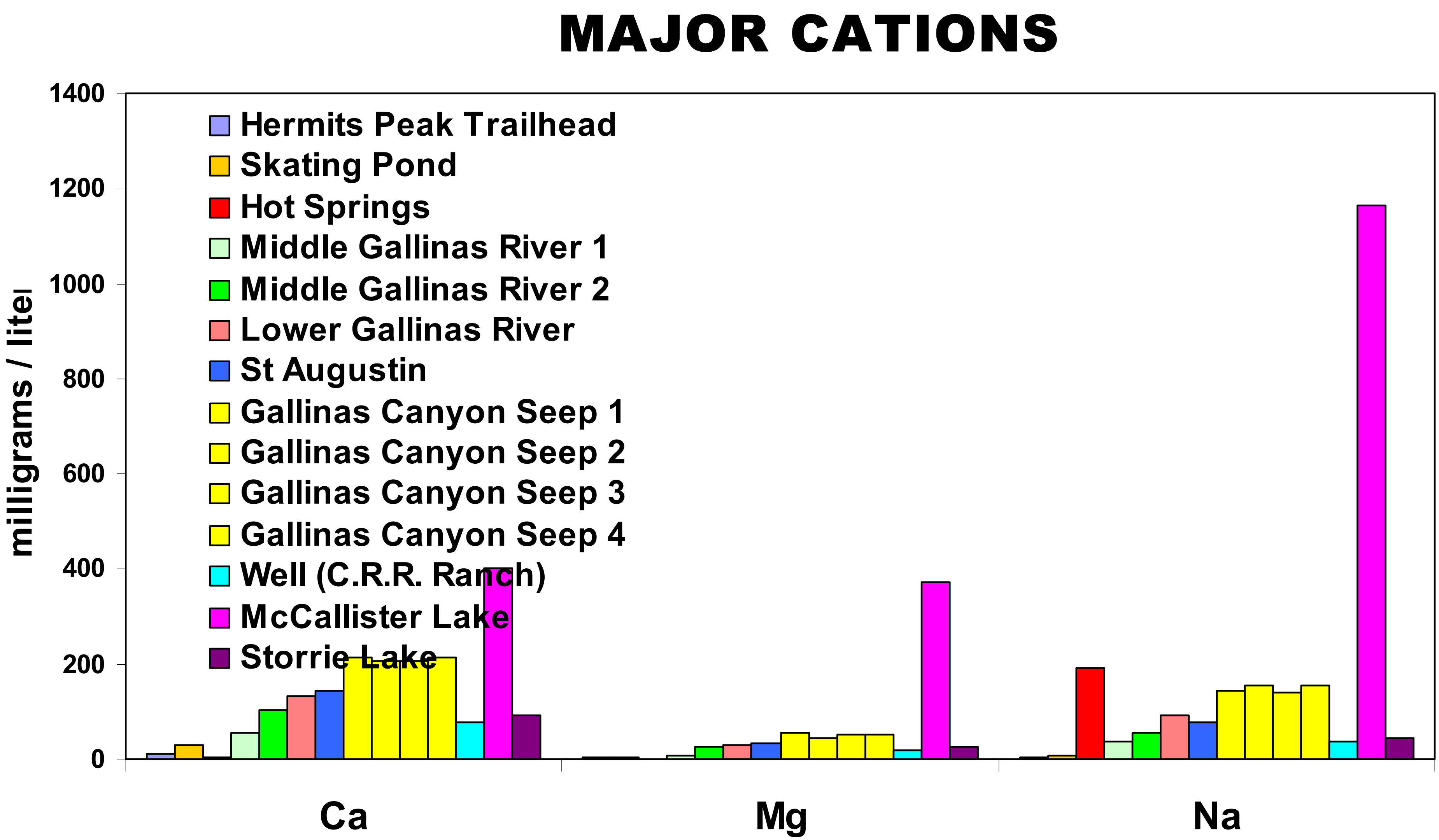


Figure 5. Histogram showing major cation concentrations in the sampled waters.

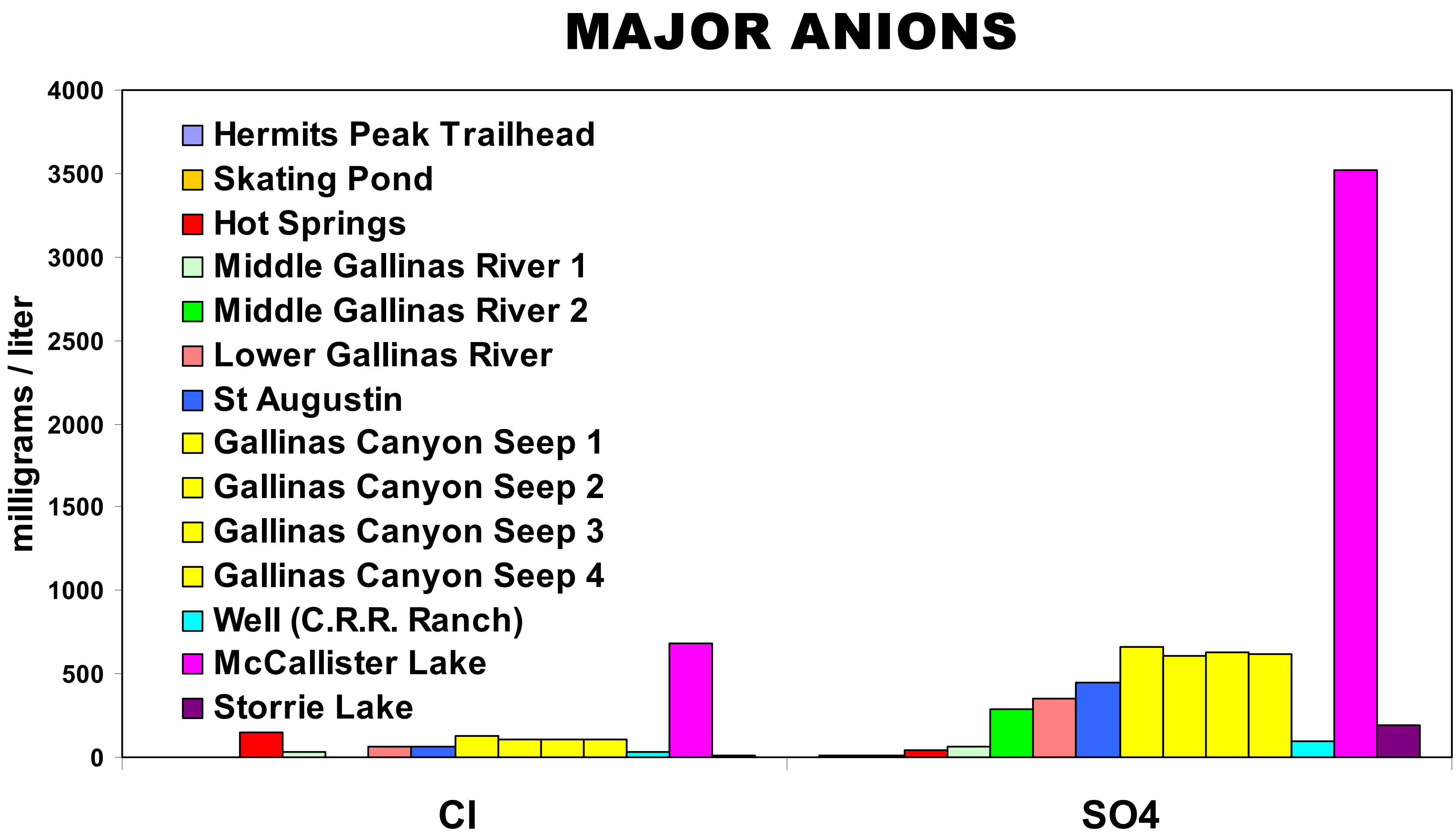


Figure 6. Histogram showing major anion concentrations in the sampled waters.

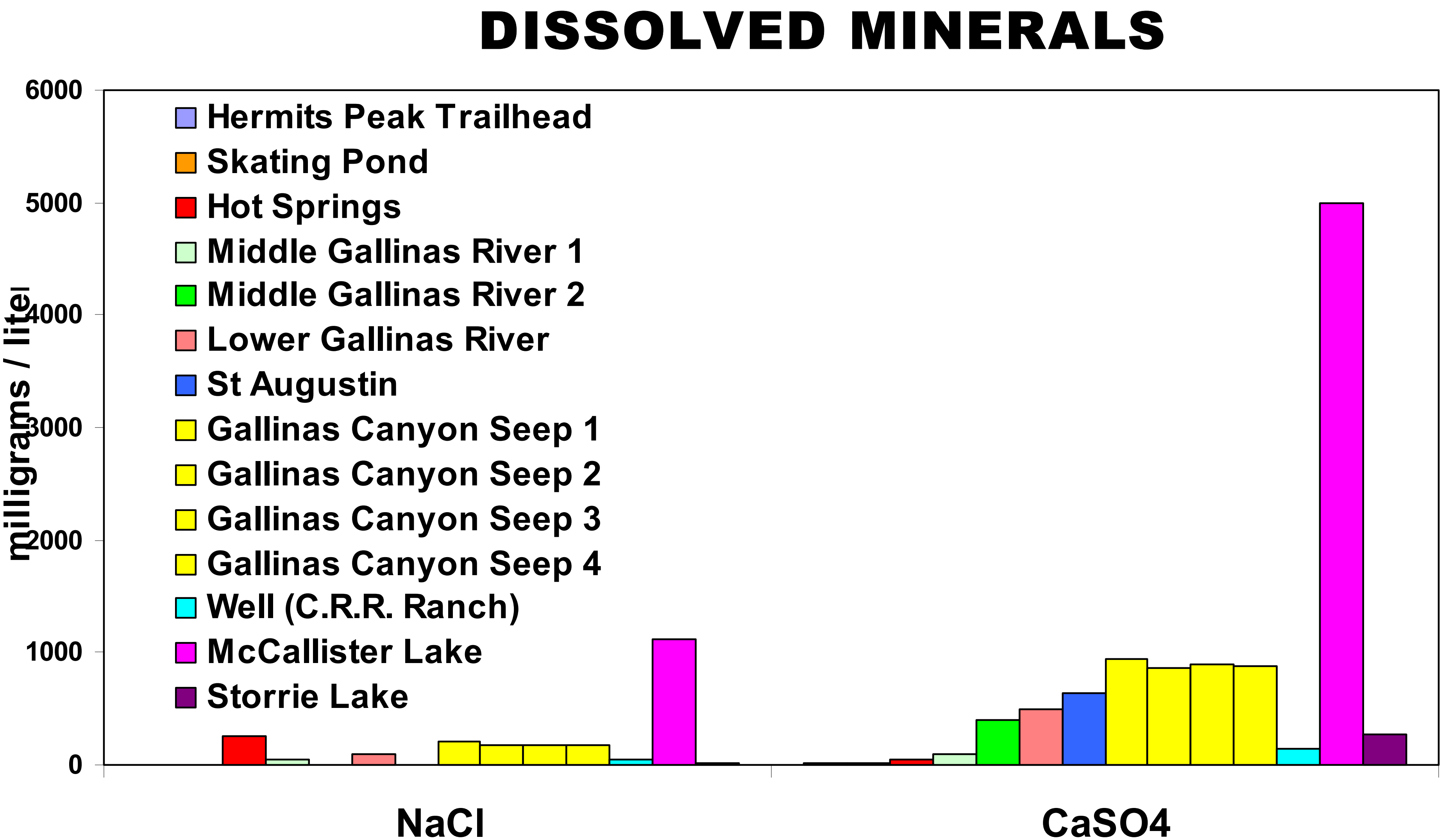


Figure 7. Histogram showing dissolved halite (NaCl) and gypsum ($CaSO_4$) concentrations in the sampled waters.

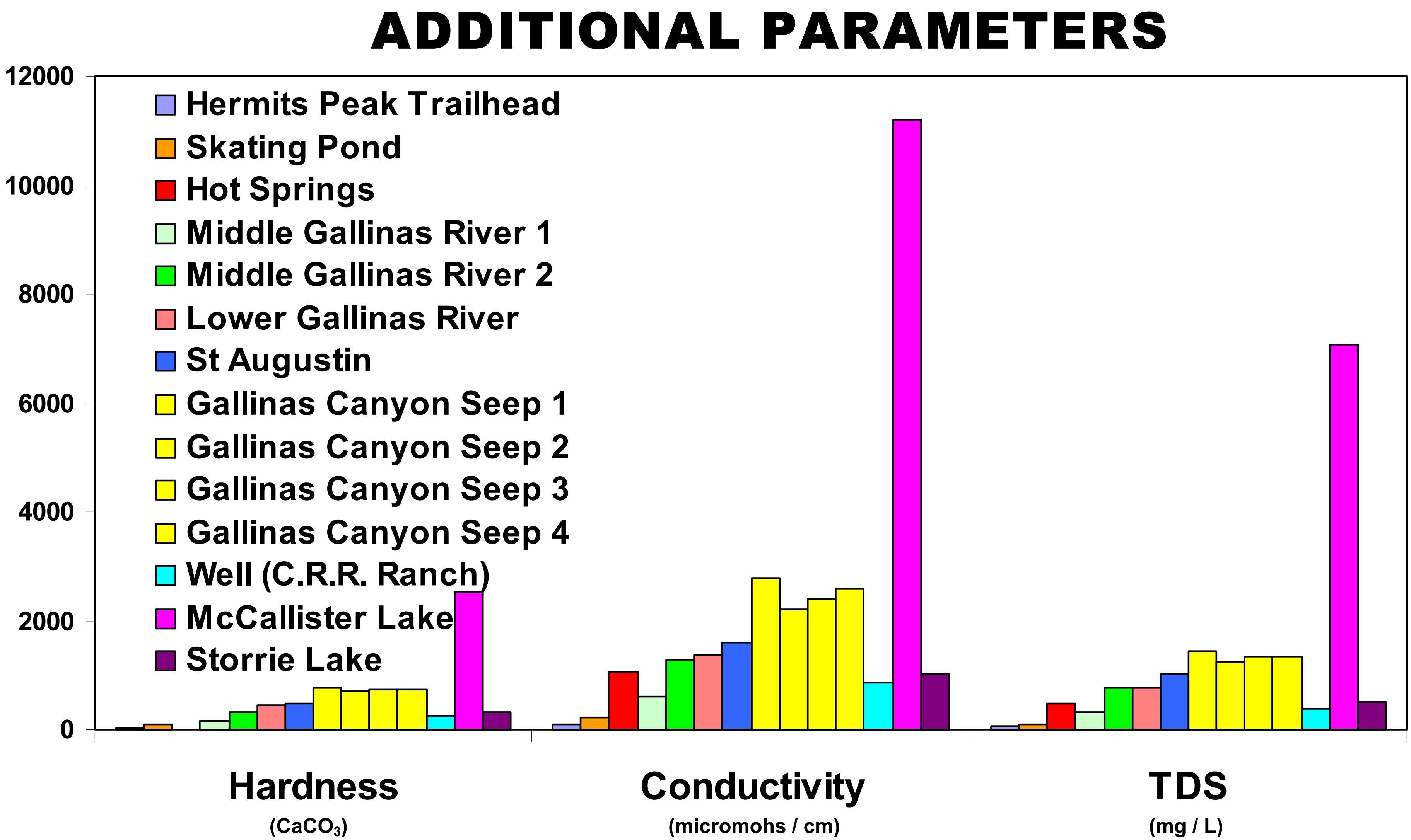


Figure 8. Histogram showing hardness, conductivity, and total dissolved solid (TDS) measurements in the sampled waters.

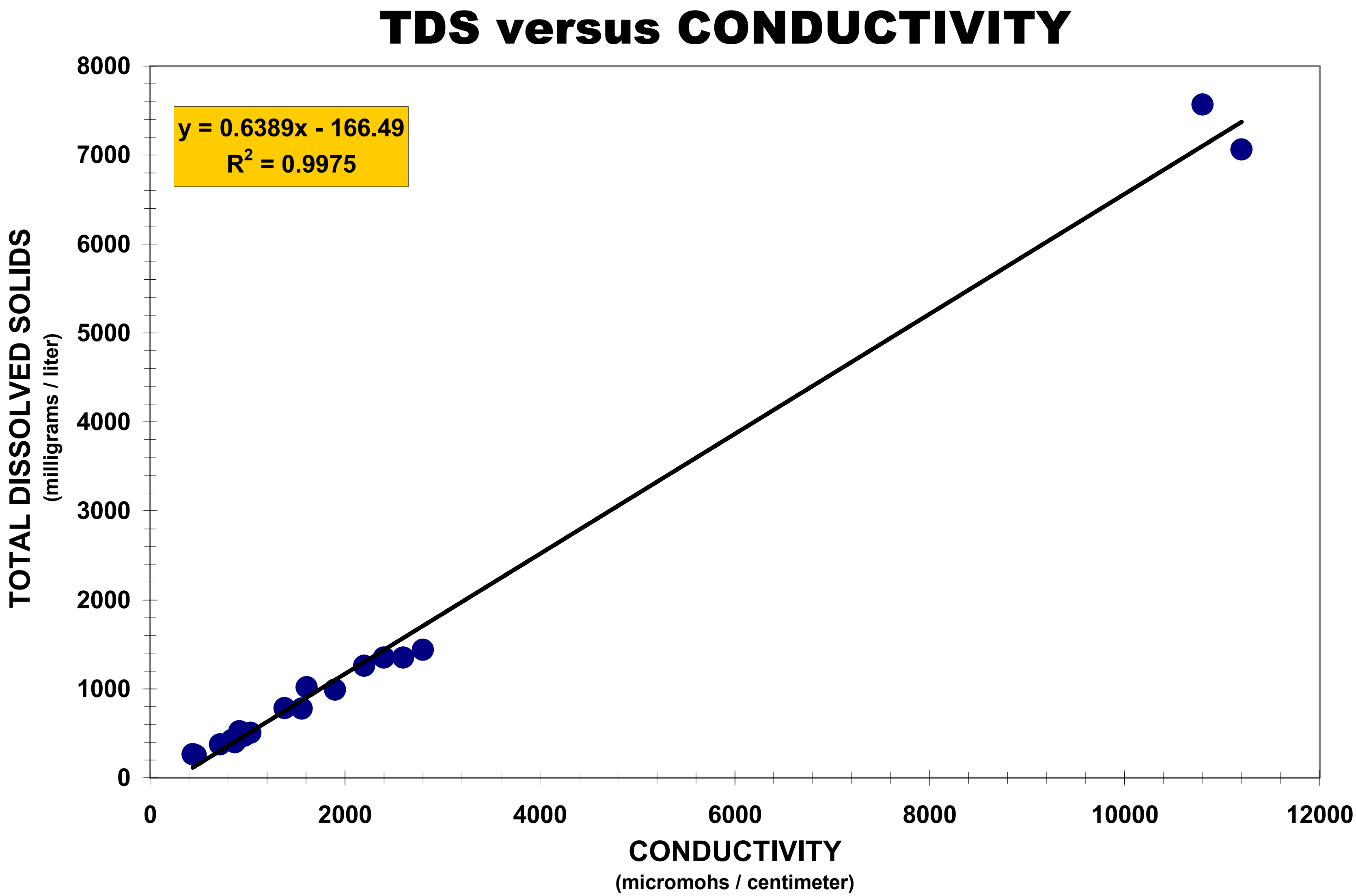


Figure 9. Graph showing strong correlation between measured total dissolved solids and conductivity in the sampled waters.