

Urban Impacts on the Chemistry of Shallow Groundwater: Barton Creek Watershed, Austin, Texas

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ABSTRACT

The Barton Creek watershed west of the Balcones Fault Zone in Austin, Texas is primarily underlain by the Glen Rose Formation. Groundwater discharges from springs in the Glen Rose limestone and from small contact springs at the base of terrace deposits along the creek mainstream. Analysis of spring samples indicates that the chemistry of shallow groundwater is altered in springs with urban development in contributing recharge areas.

Comparisons between springs in rural settings and springs in urban settings indicate significant differences in nitrate, ammonia, total Kjeldahl nitrogen, calcium, magnesium, sodium, potassium, chloride, sulfate, alkalinity, specific conductance, and total dissolved solids. Mean concentrations of nitrates in urban springs are over 500% higher and ion concentrations range from 25% to over 700% greater than those in rural springs. Results of heavy metal analyses are statistically inconclusive although heavy metals are more frequently detected in urban springs. In some cases, spring chemistry and discharge rate appear to be affected by effluent irrigation in recharge areas. Chemistry of some springs varies considerably depending on antecedent moisture conditions. Wet weather

typically dilutes nutrients and ions associated with effluent irrigation.

The relationship between urbanization and groundwater chemistry does not appear to be caused by changes in host rocks as most springs discharge from the Glen Rose Formation. Potential sources for increasing nitrogen concentrations in urban areas include landscape fertilizers and wastewater effluent. Increases in ions in urban areas may result from enhanced carbonate dissolution by irrigation with municipal drinking water and high ion concentrations in irrigated wastewater effluent.

INTRODUCTION

The Barton Creek watershed encompasses 120 square miles west of Austin, Texas with headwaters approximately 21 miles west of town and emptying into the Colorado River near the center of town (Fig. 1). Barton Creek is an important resource for the Austin community. Its crystal clear waters and nearly pristine water quality are a unique community attribute because it is so close to the urbanized center of the city. Seven miles of greenbelt along the lowermost creek reach provide abundant recreational opportunities

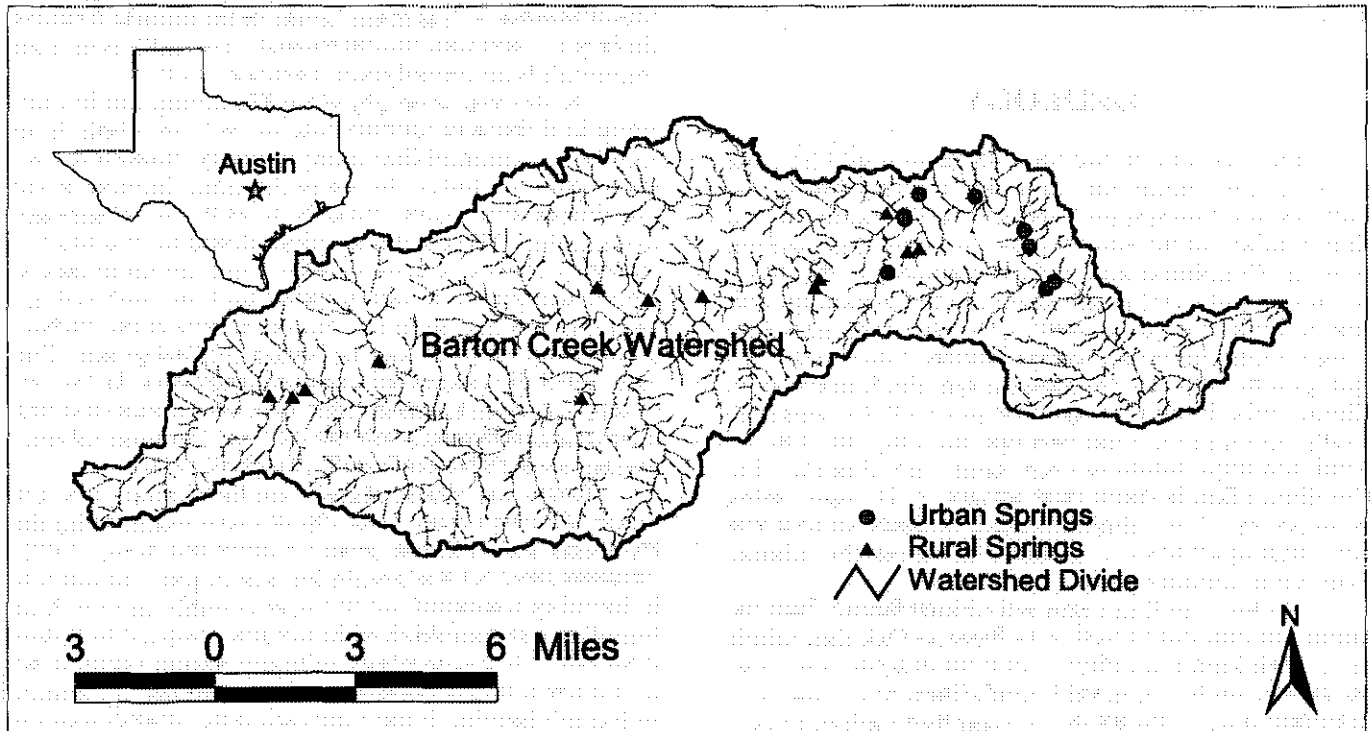


Figure 1. Map showing Barton Creek watershed and location of urban and rural spring sample sites.

for hiking, biking, swimming, fishing, and general outdoor enjoyment. Barton Creek also recharges the Barton Springs segment of the Edwards Aquifer which feeds Barton Springs, the only known habitat for the endangered Barton Springs salamander. Barton Creek and Barton Springs are also drinking water supply sources, discharging to Town Lake upstream of the City of Austin (COA) Green Water Treatment Plant.

Springs are a vital component of the Barton Creek ecosystem. They discharge from shallow groundwater tables, which store infiltrated water following rains, to creeks and tributaries at discrete points (springs) or as diffuse discharge along the banks and channel bottoms. Spring discharge is important because it maintains creek base flow, it sustains pool levels in Barton Creek, it provides fresh water at stable temperatures, and it contributes nutrients to the ecosystem. Springs are literally the life blood of a surface water system.

Urban growth, attracted by clear Hill Country creeks and scenic vistas, covers large areas of the lower watershed with a mixture of residential, commercial, and recreational development. Concerns of water quality degradation in Barton Creek from point and non-point source pollution have accompanied development. In response, the COA has enacted land use ordinances and the Watershed Protection Department (WPD) monitors surface and groundwater quality in the watershed. Analysis of water chemistry in springs provides data to determine diffuse chemical inputs to the surface water system that are derived from natural sources or human activities and can help determine the effects of chronic or catastrophic activities in spring recharge areas.

This report focuses on impacts of urban development to shallow groundwater systems in the Glen Rose Formation and local terrace deposits as determined by comparisons in water chemistry between spring sites. Monitoring goals of the WPD include characterizing overall groundwater quality in the Barton Creek watershed as well as determining baseline water chemistry in rural areas and determining the effects of urbanization on groundwater chemistry.

GEOLOGY

The Barton Creek watershed begins west of Austin and winds its way through the Texas Hill Country, crossing the Balcones Fault Zone to its confluence with the Colorado River. The fault zone divides the watershed into two major hydrogeologic units: the Contributing Zone and Recharge Zone of the Barton Springs segment of the Edwards Aquifer. In the Contributing Zone, Barton Creek is a gaining creek with water discharging from numerous small springs and seepage horizons. Contributing Zone geology is dominated by the Cretaceous-age Glen Rose Formation (Barnes, 1974, 1981). Outcrops of the younger Walnut Formation locally cap some hills. Quaternary-age terrace deposits of Barton Creek and major tributaries occur along main channels. The Contributing Zone in Barton Creek accounts for 112 square miles, or 94 percent, of the watershed, whereas the Recharge Zone area totals eight square miles, or six percent of the watershed (Santos, Loomis and Associates, 1995).

The Recharge Zone begins at the Mount Bonnell Fault, the largest and western-most fault in the Balcones Fault Zone (Slagle et al., 1986; Small et al., 1996). This is where aquifer host rocks, the Georgetown Formation and Edwards Group limestones, occur at the land surface. Here the creek changes from a gaining creek to a losing creek. Recharging waters enter the Barton Springs segment of the Edwards Aquifer, a karst aquifer, and discharge from Barton Springs, the fourth largest spring in the state (Bruni, 1981),

and other smaller springs along the Colorado River. Water loss can be rapid in the Recharge Zone, entering the aquifer through karst recharge features such as faults, fractures, sinkholes, caves, and vugs within the exposed bedrock.

Hydrogeologic Systems of Barton Creek

Springs in the Contributing Zone discharge from two hydrogeologic systems: the Glen Rose limestone and terrace/alluvial deposits. The occurrence of groundwater is highly localized and typically provides only modest volumes of water. Ranchers using wells for stock watering or to maintain the water level in a stock tank are primary consumers of these shallow groundwater resources.

Springs which issue from the limestones and dolomites of the Glen Rose Formation are found at the head of incised drainages, along rock walls of drainages, and at bedding plane contacts. Many perennial springs are found in the Contributing Zone, but most springs of the Glen Rose are ephemeral. Springs may be identified during dry conditions by mesic vegetation, including maidenhair fern and spike rush, by the presence of travertine deposits, and pools which form below the point of discharge. Typically, the discharge rate of Glen Rose Formation springs ranges from less than one gallon per minute (gpm) to approximately 10 gpm. Discharge rates are highly dependent upon antecedent weather conditions and may vary substantially. Some springs appear to sustain relatively high discharges even during droughts (such as in 1996 when most springs completely dried up) because of frequent irrigation in their recharge areas.

The most common zone of spring discharge in the Glen Rose Formation is porous Member 3 dolomitic limestone layer (Rodda et al., 1970; Garner and Young, 1976). This 70-foot-thick nodular dolomite and dolomitic limestone has a honeycombed texture which permits easy infiltration of rainwater into the exposed rock. Water migrates through the inter-connected pores to emerge at the base of Member 3. The grainy texture of the dolomite functions similarly to a sand body and can transmit water readily even in the absence of a honeycombed texture (Woodruff, 1993).

The stair-step topography of the Hill Country, with its alternating hard limestone/dolomite beds and soft marly beds, is an important component of Hill Country hydrology. Recharge to shallow groundwater bodies, the source for spring discharge in the Contributing Zone, occurs primarily as infiltration of rainwater through soils. This stair-step hydrologic system forms a series of shallow groundwater reservoirs in which water is slowly released to surface drainages or is utilized by grasses and trees. Infiltrated rainwater may pass through several stair-step systems before reaching surface water, each time filtering through soils and grasses. This local hydrologic process has important implications in the Hill Country for stream hydrology (short term water storage) and land management (minimizing disturbance of local flow paths and maximizing natural filtration of runoff) (Woodruff, 1993).

Terrace and alluvial deposits are found along the entire course of Barton Creek. These deposits accumulated during the Pleistocene and Holocene periods (Garner and Young, 1976). Thickness varies but it is typically less than 30 feet. The sediment is derived by mechanical weathering of primarily the Glen Rose Formation, with some debris of the Edwards Group and the Walnut Formation. Thick accumulation of terrace deposits occurs in the downstream portion of Barton Creek, particularly near confluences with large tributaries. In other locations, terrace deposits accumulate on the inside portion of meander loops of the creek.

Rain water infiltration, groundwater, and possibly periodic overbank flow of Barton Creek water, accumulate within the grav-

el deposits to form local, shallow groundwater systems. Springs are found discharging from several terrace deposits along Barton Creek, particularly in the downstream portion of the Contributing Zone. In some cases, terrace/alluvial systems may also receive water from Glen Rose springs buried by ancestral Barton Creek.

METHODS

Groundwater in the Barton Creek watershed is monitored by collection and chemical analyses of spring water samples. This report includes data collected between September 1990 and March 1998. Field parameters have been tested at 26 springs, 10 urban springs and 16 rural springs (Fig. 1). These measurements typically include pH, temperature, total dissolved solids, specific conductance, and turbidity. Laboratory testing has been conducted on samples from 18 springs, nine urban springs and nine rural springs. Estimates of spring discharge are made at the time of sample collection by visual examination of the flow volume, by direct measurement of the rate at which water fills a container of specific volume, or by velocity meter.

The COA analyzes groundwater samples for selected chemicals listed in the Environmental Protection Agency primary drinking water standards in addition to many other indicator parameters. Parameter selection balances health and environmental hazards with sample costs. The resulting list of analytical parameters includes bacteria, nutrients, total organic carbon, major ions, and six heavy metals. Nitrogen testing includes nitrate+nitrite as nitrogen. Since nitrite is rarely detected in this area, results of nitrate-nitrite tests will be assumed to be all nitrate. Five samples from two urban sites have been tested for a broad suite of metals and organic compounds. Comprehensive suites of organic compounds are too costly to test for on a regular basis at all springs. Drinking water standards are used only as a guide or reference point for groundwater results; environmental impacts can occur at far lower constituent concentrations. Some analyses of nitrate+nitrite-nitrogen, orthophosphorus, and ammonia-nitrogen are performed in the WPD in-house laboratory using a Hach DR2000 spectrophotometer. Most samples have been analyzed by the COA's Water and Wastewater Department Environmental Laboratory or other contract laboratories.

The results of laboratory analyses of groundwater are evaluated for data accuracy. Approximately 10 percent of samples collected are field duplicates. Duplicates are compared for consistency, and constituents with wide deviation in duplicate analyses are omitted from data analysis. Outliers are evaluated by examining previous data from the site or data from similar sites. A charge balance calculation is done for each ion analysis. Hounslow (1995) and Freeze and Cherry (1979) recommend that only analyses with a charge balance less than five percent be accepted. However, contract laboratories generally have broader ion balance ranges than research laboratories. Twenty percent was selected as the cutoff limit for acceptance of analyses. The range of charge balances for samples included in this report is -15.9 percent to +17.5 percent.

For analysis and evaluation, groundwater analyses were grouped as rural or urban for the purposes of statistical evaluation. Springs located in areas near and down gradient of residential, commercial, industrial buildings, high capacity roadways, or golf courses were classified in the urban group. Springs found in nature preserves, ranches, or low density residential development (<1 home/10 acres) were categorized in the rural group.

Results from field and laboratory testing were interpreted using several different methods. Statistical tests were conducted on all parameters except heavy metals. Data were tested for normality

using the Shapiro-Wilk Normality Test. Data for all non-normal parameters were analyzed using ranked values. Values of one-half of the detection limit were used for all Analysis of Variance (ANOVA) testing of non-detection results and then confirmed using two-sample t-tests which employed the Robust-Log Probability Regression Method to evaluate non-detection values. Data from rural and urban groups were compared using an ANOVA for normally distributed data and Wilcoxon Rank-Sum Test for all non-normal data. A significance level of 0.05 was used for identifying statistically significant differences between the urban and rural groups of data. To determine significant differences within rural and urban groups, a Duncan's Multiple Range Test was used in conjunction with ANOVA procedures employing specified contrasts to check if any significant sub-groups could be delineated. Temporal trends with data were tested using linear regression. All statistical tests were performed using General Linear Models Procedure available in the SAS software package from the SAS Institute.

Ion data were plotted on Piper diagrams to classify the waters chemically and determine if there were differences within grouped data sets or within specific sites. Bivariate analyses were conducted to determine relationships between parameters and to identify time trends within data sets. Grouped data were examined to determine time trends, urban impact signature fields for classification groups, or other environmental factors affecting spring chemistry.

RESULTS

Groundwater quality is generally good in springs in the Contributing Zone of Barton Creek, although localized degradation is evident based on differences in water chemistry in urban and rural data sets. As a point of reference, no samples exceed the primary drinking water standard maximum concentration levels (TAC, 1994) for any parameter except bacteria. Secondary drinking water standards have been exceeded only by iron in a single sample, zinc in several samples, and pH in numerous samples. No synthetic organic chemicals have been detected during this study in five different samples at two springs. Copper, lead, and nickel have been detected below drinking water standards at several springs.

A large number of spring samples exceed surface water standards and screening levels developed by the Texas Natural Resource Conservation Commission for segment 1430 (Barton Creek) of the Colorado River (TNRCC, 1996). Chloride and sulfate exceed the 40 mg/L standard in 20 and 21 samples respectively, 18 samples exceed the 500 mg/L TDS standard, 43 samples exceed the 1.0 mg/L nitrate-nitrogen screening level, and 3 samples exceed the 0.1 mg/L orthophosphorus screening level. All but three samples were from urban springs. Normally, groundwater concentrations for most constituents are greater than surface water concentrations. However, the fact that most of the samples that exceed surface water standards or screening levels are from urban sites suggests that continued urban growth will increase groundwater discharges with elevated concentrations of constituents. As a result, Barton Creek surface waters may eventually exceed current state standards for these constituents.

A Piper plot of ion results from all sampled springs is shown in Figure 2. As evident on the diagram, the chemistry expressed in these springs ranges from calcium-bicarbonate to calcium+sodium-mixed anion waters. This figure shows little spread in rural spring samples, but much wider range in those of urban springs. Ions are used in this groundwater study as an indicator of differences in water quality. Elevated levels of ions may not indicate detrimental

effects but merely a change to groundwater resources from urbanization with other formation variables constant.

Comparisons Between Urban and Rural Springs

Potential groundwater chemistry impacts that are due to anthropogenic influences have been investigated by comparison of parameter concentrations. Statistical evaluation indicates a relationship between urbanization and changes in groundwater chemistry. Many of the springs in urban settings are in areas downgradient of wastewater effluent irrigation fields (golf courses or native landscape). This factor may have influenced the magnitude of chemical differences between urban and rural sites but does not explain all of the chemical differences observed.

Results of the statistical evaluation reveal a statistically significant difference between urban and rural groups for twelve parameters at the 95 percent confidence level. These parameters are specific conductance, total dissolved solids (TDS), nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen (TKN), calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Fluoride and total organic carbon (TOC) show significant differences at the 90 percent confidence level. Summary statistics of results from the urban and rural groups for these are shown in Table 1.

Currently there are insufficient data to determine if heavy

metal occurrences in urban springs exceed background concentrations because of variable detection limits and lack of detectable concentrations, although 21 of 28 (75%) of the heavy metal detections are in urban springs.

Statistics indicate striking differences in chemical composition of waters from urban and rural spring settings. The amount of change from rural to urban springs in the twelve parameters with significant differences ranges from 25 to over 700 percent, all increasing in urban sites. The greatest increases are present in nitrate (580%), sodium (750%), potassium (330%), chloride (590%), and sulfate (360%).

The dramatic differences in ion concentrations are evident when plotted on a Piper diagram, commonly used to classify groundwater chemistry types (Fig. 2). Rural sites tend to cluster in the calcium-bicarbonate area of the diagram. Urban sites have greater variability, showing increasing sodium, chloride, and sulfate content, in the mixed ion region of the diagram above the 20 percent sulfate+chloride line.

Significant differences in some constituents occur between individual springs within urban and rural groups but not in an identifiable pattern. However, springs downgradient of effluent irrigation fields tend to have higher concentrations of constituents.

Bivariate analysis of springs in urban and rural settings was conducted to determine if there were any subtle relationships between chemical parameters and determine signature fields for site groups. Previous COA studies of groundwater from springs in

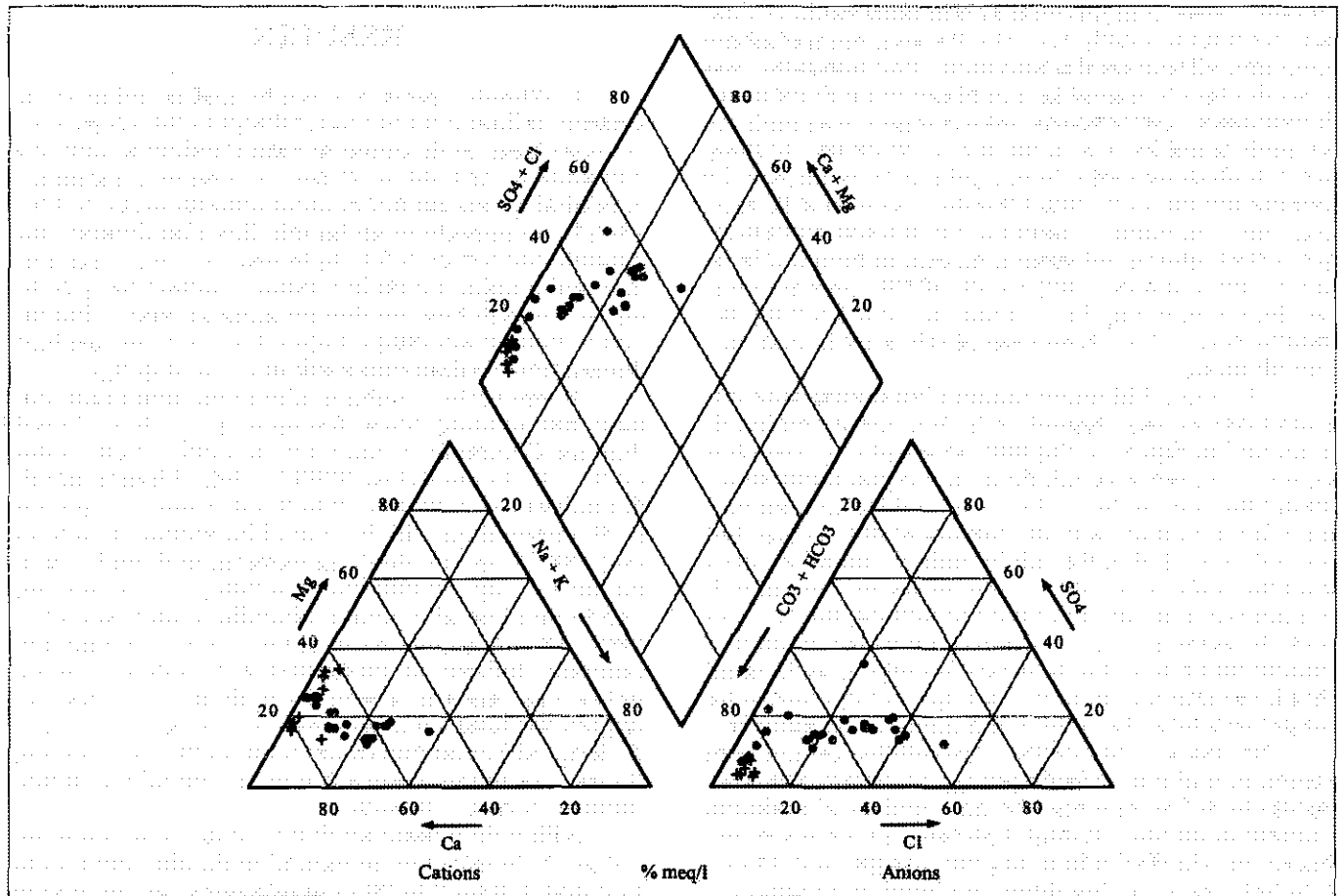


Figure 2. Piper plot of ions in samples from urban (filled circles) and rural (pluses) in Contributing Zone of Barton Creek watershed illustrating chemical differences between the two groups of springs.

Date 9/10-3/98	pH	Temp	Turbidity	Specific Conductance	Total Dissolved Solids	NO3-N	NH3-N	Total Kjeldahl Nitrogen	Ortho-P
		C	NTU	us/cm	mg/L	mg/L	mg/L	mg/L	mg/L
Urban									
Mean	7.27	21.14	2.4	1026	448	1.40	0.03	0.30	0.03
Median	7.38	20.55	1.7	1012	441	1.75	0.01	0.25	0.02
Maximum	8.12	23	14.0	1660	748	5	0.20	0.99	0.23
Minimum	6.73	15	0	517	230	0.05	0.005	0.05	0.01
Count	78	52	45	45	60	76	73	29	76
Non-detected						5	31	8	26
Rural									
Mean	7.45	20.66	1.7	561	243	0.21	0.02	0.11	0.04
Median	7.29	21	1.0	549	240	0.08	0.01	0.05	0.02
Maximum	8.30	26	4.0	644	320	1	0.07	0.34	0.13
Minimum	6.90	7	0	456	150	0.005	0.005	0.05	0.01
Count	22	22	15	10	15	18	16	11	18
Non-detected						4	10	8	10
	Total P	Total Organic Carbon	Fecal Coliform	Mg	Ca	Na	K	Cl	Sr
	mg/L	mg/L	#/100 ml	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Urban									
Mean	0.02	9.39	13	22.46	132.52	41.28	2.35	93.73	74.45
Median	0.01	2.31	5	21.68	127.0	35.06	1.87	95.26	73.30
Maximum	0.08	74.8	158	26.88	170	120	5.20	266	220
Minimum	0.005	1.06	0.5	15.10	92	9.26	0.50	8.25	19
Count	29	28	39	26	25	26	25	26	26
Non-detected	19		14				5		
Rural									
Mean	0.02	4.78	18	16.38	83.82	4.81	0.54	13.06	15.89
Median	0.02	2.19	7	16.87	81.35	3.42	0.5	11.2	15.25
Maximum	0.03	18.3	48	21.71	117.5	16.4	0.85	36.4	40
Minimum	0.02	0.86	2	10.6	54.2	2.86	0.5	7.09	8.09
Count	5	9	6	10	10	10	10	10	10
Non-detected							9		
	F	Al	Ba	Cu	Fe	Pb	Ni	Se	Zn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Urban									
Mean	0.16	321	0.0352	0.0064	0.1674	0.003	0.0027	0.426	76.24
Median	0.14	320	0.037	0.0060	0.0063	0.003	0.0027	3.4	86
Maximum	0.44	410	0.05	0.0110	2.1003	0.003	0.0027	3.545	142.7
Minimum	0.03	244	0.018	0.0023	0.0021	0.003	0.0027	0.388	0.01
Count	28	25	5	3	19	1	1	5	3
Non-detected				25	18	26	23		10
Rural									
Mean	0.12	255			0.1255				33
Median	0.11	248			0.0081				33
Maximum	0.2	320	0	0	0.8150	0	0	0	121
Minimum	0.07	220	0	0	0.0038	0	0	0	45
Count	10	10	0	0	5	5	0	0	2
Non-detected				11	6	11	9		4

Sr, As, Se, Ba, Cd, Cr, Mn, Hg, Mo, Sn, Ag, Ti tested for but not detected

Non-detects set to 1/2 detection limit for statistical analysis except for heavy metals

Table 1. Summary results of urban and rural spring samples from the Contributing Zone of the Barton Creek watershed.

the Bull Creek watershed have identified differences in total dissolved solids, nitrate-nitrogen, chloride, sulfate, potassium, sodium, calcium, and magnesium between springs in urban areas and those in rural areas (COA, 1993; Johns, 1994).

Figure 3 illustrates the differences between two constituents, specific conductance and nitrate, with significant differences in concentrations from urban and rural sites. Samples from rural sites can be characterized by plotting below approximately 700 $\mu\text{S}/\text{cm}$ specific conductance, and less than 0.5 mg/L nitrate-nitrogen. Samples from urban sites generally plot greater than 800 $\mu\text{S}/\text{cm}$ specific conductance and greater than 1.0 mg/L nitrate-nitrogen. Some exceptions are present in the urban samples where several plot close to rural points. These samples were all collected during very wet conditions and may have diluted urban signatures.

Figure 4 illustrates the signature of sodium and sulfate from springs in urban and rural settings. A field defining an area in which impacts due to urbanization occur can be drawn at greater than 40 mg/L sulfate and 20 mg/L sodium. The urban points plotting within the rural area were collected during very wet conditions, which probably affected constituent concentrations. The rural spring within the urban field may be affected by a small ranching operation and a ranch house septic system.

Groundwater studies in New York and Florida identified similar trends in data when comparing urban and rural sites (Eckhardt and Stackelberg, 1995; German, 1996). In New York, the authors identified median concentrations of nitrate below four mg/L in undeveloped sites and median concentrations of five to nine mg/L in developed sites. The sources of nitrate identified for the study area include nitrogen fertilizers and sewage wastes. In Florida, specific conductance values and concentrations of calcium, sodium, potassium, sulfate, chloride, ammonia, orthophosphorus, and total phosphorus were significantly higher in developed areas than in control (undeveloped) areas.

Environmental impacts of elevated concentrations of constituents from urban springs on surface water depends on many factors, including loading to the receiving water, receiving water flow conditions, and the chemical behavior of the constituent. Direct human consumption of spring water, and thus comparisons with drinking water standards, is not currently a concern since there are few shallow water wells and spring waters have opportunity to mix with large volumes of surface water prior to possible uptake by water treatment plants. Ecological impacts are a more immediate concern because they occur at far lower concentrations than human health problems. Impacts of ions are difficult to identify and potentially may be partly mitigated by increased travertine deposition at spring heads. Bioassessment strategies that examine aquatic organisms may prove useful for detecting ecological impacts of elevated ion concentrations.

Higher nutrient concentrations will have more visible results. Hill Country creeks tend to have low concentrations of nitrogen and phosphorus resulting in limited algae growth (COA, 1997). Increases in the local nutrient loads can initiate algae blooms which not only impact the aesthetic qualities of the creek but can cause dramatic reductions in dissolved oxygen levels when the algae begin to decay. Surface water chemical analyses indicate that elevated nitrate concentrations occur in a pool downstream of one large spring affected by nearby urban development. The pool downstream of LC Spring had a mean nitrate-nitrogen concentration 0.31 mg/L , which is higher than in any other monitored pool in Barton Creek (means ranging from 0.05 to 0.1 mg/L nitrate-nitrogen) (COA, 1997). This pool has had re-occurring algae blooms. Impacts are particularly apparent during very low creek flow conditions.

DISCUSSION

The differences in groundwater chemistry between urban and rural sites in the Barton Creek watershed are distinct. An urban groundwater signature can be defined using constituents with the greatest differences (Table 2). These signature values may differ in other geologic formations in the Austin area. The precise causes of all these differences are unclear although in some cases possible sources can be identified.

The relationship between urbanization and groundwater chemistry does not appear to be caused by changes in host rocks as many springs discharge from the same geologic unit, the Glen Rose Formation, and even the same member within the Glen Rose. Water from the lower Glen Rose, Member 1, can have high concentrations of some constituents, particularly sulfate, which may yield a false urban groundwater signature. However, the lower Glen Rose does not crop out in the Barton Creek basin (Bruno and Duffin, 1983; Barnes, 1974) and, therefore, is unlikely the source of water causing these differences in groundwater chemistry. In the case of springs discharging from Barton Creek terraces, their occurrence is so localized that variations in the chemical signature of the terrace/alluvial deposit springs most likely result from local impacts.

Possible explanations for higher nitrogen concentrations in urban springs include fertilizers, wastewater, and atmospheric deposition. Dry deposition (dust) and emissions may raise the nitrate and ammonia concentrations in rainfall. Recent studies conducted in the Delaware Bay (Scudlark and Church, 1993) indicate that 26 percent of the summer total dissolved inorganic nitrogen flux is from atmospheric input. Rainwater has also been considered as a potential source of elevated nitrate concentrations in springs. The COA collected rainwater samples at a water quality pond located in southeast Austin during eight rain events in 1995. Total nitrogen concentrations were insufficient to account for all nitrogen in urban springs. Therefore, additional sources must provide the nitrogen.

Nitrogen isotopes were used to investigate potential sources of nitrogen at selected sites (Table 3). Nitrogen isotope ratios greater than 10 are generally considered indicative of a wastewater source of nitrogen, between six and 10 may indicate a fertilizer source and less than six may indicate natural soil nitrogen (Kreitler, 1975; Browning, 1977). Three springs are downgradient of either golf courses or fields of native vegetation irrigated with wastewater effluent: LC, LJ, and BSB. LJ Spring consistently has nitrogen isotope ratios in a range from five to seven and are similar to a golf course holding pond up gradient of the spring (Table 3). At this golf course, effluent is mixed with lake water which dilutes nitrogen concentrations and decreases the isotopic ratio. Nitrogen isotope ratios for BSB and LC Springs show wide variation, ranging from heavier ratios suggesting a wastewater source of nitrogen to lighter ratios suggesting a fertilizer or natural soil nitrogen source. These variations may result from different moisture conditions prior to sampling. Samples from irrigation holding ponds upgradient of LC Spring have a heavy isotopic ratio indicative of wastewater. SWP Spring underlies a lightly traveled six lane highway but shows a similar range in isotopic ratios. However, there are no apparent wastewater sources to generate the heavy nitrogen ratios. A single highway runoff sample indicated a heavy nitrogen isotope ratio (Table 3). Therefore, the heavier ratio at SWP Spring may be from infiltrated road runoff. A single nitrogen isotope ratio from a rural spring is in a range suggesting natural soil nitrogen. Further indications that effluent irrigation may be affecting spring water quality at these three springs include higher concentrations of

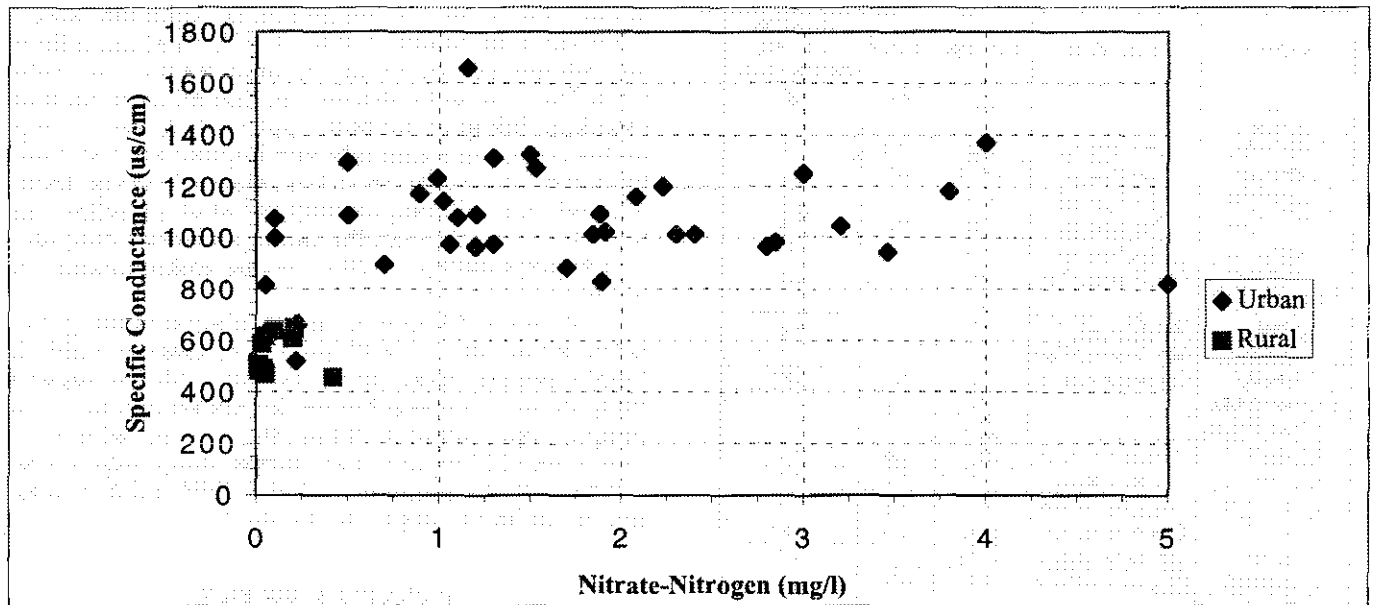


Figure 3. Bivariate diagram of nitrate and specific conductance in Barton Creek springs illustrating chemical differences between urban and rural springs. An urban groundwater signature is generally greater than 1.0 mg/l nitrate-nitrogen and greater than 800 us/cm specific conductance.

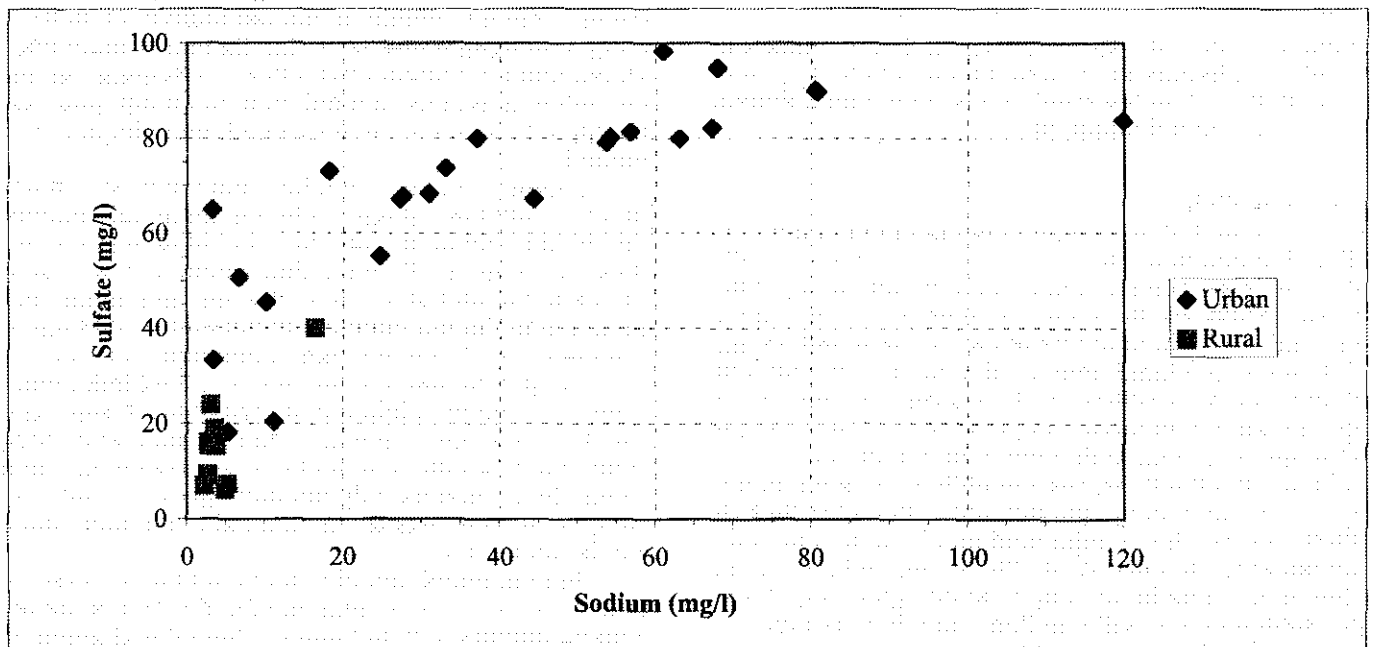


Figure 4. Bivariate diagram of sodium and sulfate in Barton Creek springs illustrating an urban groundwater signature of generally greater than 40 mg/L sulfate and greater than 20 mg/L sodium.

chloride, sulfate, and sodium than in other urban springs.

Elevated concentrations of ions such as calcium, magnesium, and bicarbonate can possibly be attributed to increased dissolution of carbonate rocks or fertilizers and soil conditioners. A method of increased dissolution has not been identified. There are two possible processes for enhanced dissolution. In urbanized areas, high pH potable water may enhance dissolution of calcium-

carbonate during irrigation, thereby increasing calcium concentrations in groundwater. Treated wastewater effluent may have a similar effect. Although most soluble at low pH, calcite, as the principal component in limestone, also can be dissolved at the higher pH of potable water. This may occur when low ionic strength tap water mixes with higher ionic strength groundwater, decreasing the activity coefficients and subsequently increasing the calcite solubility

SPRING	AQUIFER	DEL 15N	NO3-N mg/l	BARTON CREEK DISCHARGE cfs
Urban				
SWP940222	Glen Rose m3	21.5	0.4	3.9
SWP940419	Glen Rose m3	15.15	0.1	4.7
SWP950222	Glen Rose m3	11.05	0	16
BSB940504	Glen Rose m3	1.0	0.5	3.6
BSB960410	Glen Rose m3	13.1	1.5	1
LCF940222	Glen Rose m2/Terr	6.8	2.7	3.9
LC Pond 4/19/95		6.0		
LJ940215	Glen Rose m2/Terr	6.6		1.8
LJ950222	Glen Rose m2/Terr	5.1	1	16
LJ960213	Glen Rose m2/Terr	5.3	0.7	0.97
LC Pond 2/7/94		21	2.6	
LC Pond 2/13/96		22.4	4.3	
LCA940222	Glen Rose m2/Terr	22.1	2.4	3.9
LCA940419	Glen Rose m2/Terr	19	2.6	4.7
LCA950222	Glen Rose m2/Terr	4.2	0.6	16
LCA960213	Glen Rose m2/Terr	29.45	2.4	0.97
LCB940419	Glen Rose m2/Terr	12.85	2.5	4.7
LCB950222	Glen Rose m2/Terr	5.3	0.35	16
Rural				
UFT940222	Glen Rose m3	5.25	1	3.9
Miscellaneous				
Highway Runoff		11.2	0.21	
COA Tap Water		3.25	0.8	

Table 2. Characteristic urban signatures for H constituents with significant differences between urban and rural groups. A signature for ammonia was not determined because of the slight differences in data near method detection limits.

(Hounslow, 1995).

Sources of additional sodium, chloride, and sulfate are more difficult to determine. Dissolution of halite (NaCl) is a naturally occurring source of sodium and chloride, although unlikely in the shallow subsurface of the Barton Creek watershed. There are many manmade sources of sodium which can enter household sewage, including water softeners, bleach, and detergents. Irrigation with treated wastewater effluent would, therefore, be expected to increase sodium concentrations in groundwater. The large number of samples in the data set from springs in areas that appear to be influenced by effluent irrigation may artificially skew the concentration averages upward. However, data from sites in the Bull Creek watershed show a similar trend but with lower sodium concentrations in urban areas (COA, 1993; Johns, 1994). Enhanced dissolution of naturally occurring barite and gypsum may also be an important factor as well as fertilizers and soil conditioners.

Higher alkalinity concentrations in groundwater from residential areas served by conventional centralized sewer systems have been observed in Long Island, New York (Eckhardt and Stackelberg, 1995). It is likely that wastewater effluent irrigation, possibly domestic wastewater, or accelerated carbonate dissolution are the sources of elevated alkalinity observed in the Long Island study.

Some unusually large fluctuations in spring chemistry occur at LC Spring, a spring apparently affected by effluent irrigation from a nearby golf course. This spring discharges from the downstream end of an extensive deposit of terrace sediments and maintains a relatively high volume of discharge even under drought conditions. In Figures 3 and 4, some of the urban data points plotting

outside the urban impacts field are from LC Spring and were collected during wet periods. A Piper plot (Fig. 5) of data collected from this spring during wet and dry conditions (based on Barton Creek flow) shows a clear dilution trend from dry conditions to wet conditions. During dry conditions most, if not all, water discharging from the spring appears to be from irrigation water infiltrating the shallow terrace sediments and migrating to the spring. During wet conditions, infiltrating rainwater and possibly baseflow infiltration from a large tributary that crosses the terrace outcrop dominate discharge, diluting the effluent and the resulting chemical signature.

The effect of dilution on water chemistry in the spring at LC Spring is also reflected in nitrogen isotope chemistry (Table 3). Samples collected under varying climatic conditions suggest a strong inverse relationship between dry and wet conditions. For example, samples collected for two different spring outlets during a wet period (2/22/95) show a low nitrogen isotope value whereas samples under dry periods of 2/22/94, 4/19/94, and 7/13/96 had considerably higher isotopic values (Table 3).

CONCLUSIONS

Significant differences in groundwater chemistry have been identified between springs located in urban and rural areas in the Contributing Zone of the Barton Creek watershed. Higher values/concentrations of specific conductance, total dissolved solids, nitrate, ammonia, total Kjeldahl nitrogen, calcium, magnesium, sodium, potassium, chloride, sulfate, and alkalinity are found in springs discharging in urban areas. The differences between urban site and rural site parameter concentrations are statistically significant, indicating an impact of urbanization, even though groundwater quality in urban areas remains good relative to drinking water standards.

Impacts to surface waters have occurred in areas downstream of urbanized springs. Elevated nitrate concentrations detected in LC Spring have also been detected in the pool downstream of the spring. Extensive algae blooms have been documented in this reach of the creek. Surface water impacts may increase in the future as urban growth continues and discharge of groundwater with higher constituent concentrations increases.

The probable source of the nitrate in LC and BSB Springs during dry conditions is effluent holding ponds and effluent irrigation. This conclusion is supported by heavy nitrogen isotope ratios in the springs indicating a wastewater source of nitrogen. These springs also maintain relatively high discharges during prolonged drought conditions which dry up most springs and most surface flow in Barton Creek.

Bivariate analysis grouping springs into landuse categories has been effective in detecting impacts due to urbanization. Resulting diagrams allow definition of urban and rural groundwater signatures which can be applied to other watersheds in the Austin area and potentially other regions with similar geologic settings. Many signature constituents are commonly identified and inexpensive to run which can reduce costs in delineation programs.

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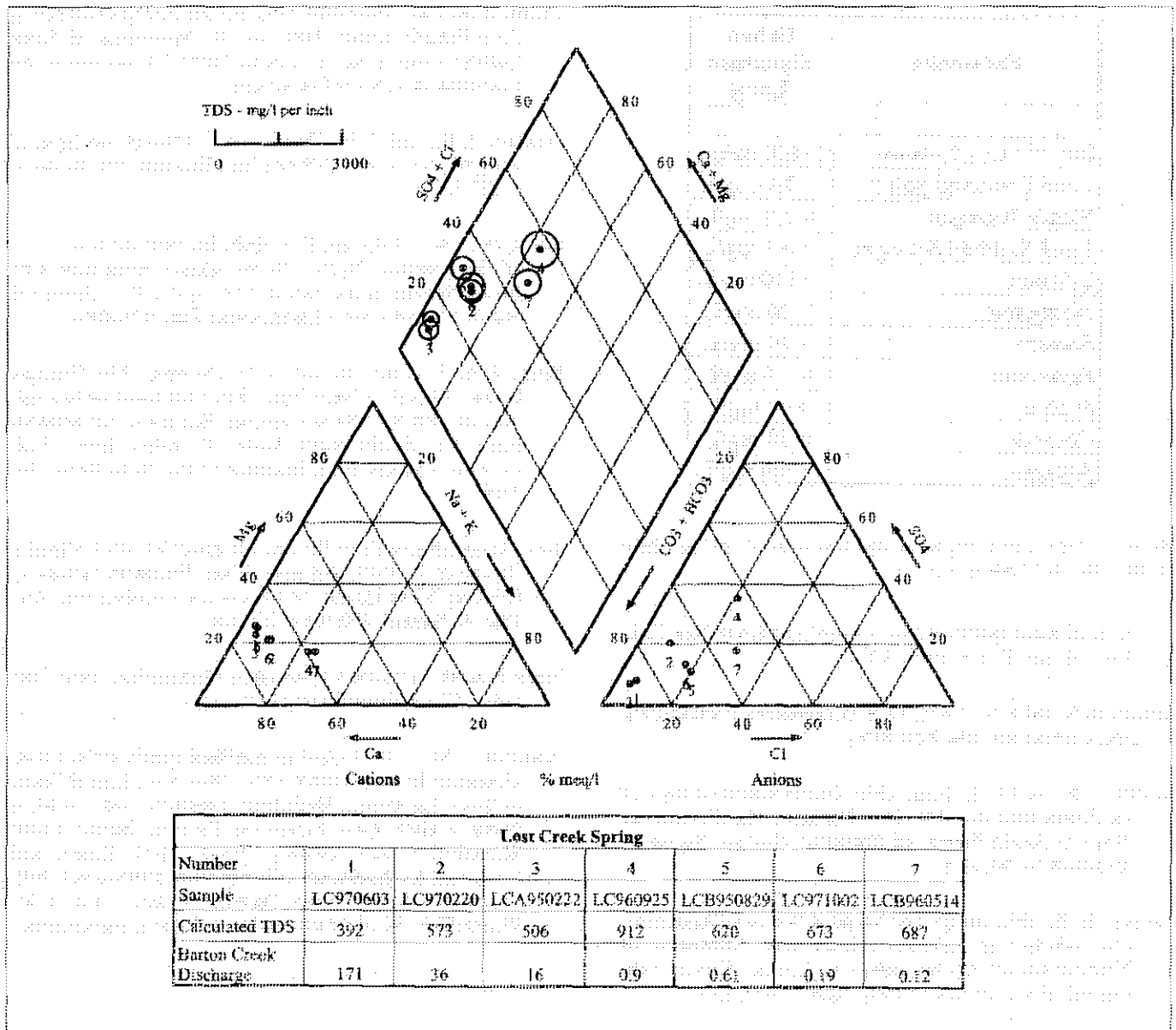


Figure 5. Samples from LC Spring on Piper diagram showing a large variation in groundwater ion chemistry resulting from changing antecedent moisture conditions.

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Parameter	Urban Signature Level
Specific Conductance	> 800 us/cm
Total Dissolved Solids	> 300 mg/L
Nitrate-Nitrogen	> 1.0 mg/L
Total Kjeldahl Nitrogen	> 0.1 mg/L
Calcium	> 110 mg/L
Magnesium	> 20 mg/L
Sodium	> 20 mg/L
Potassium	> 1.0 mg/L
Sulfate	> 40 mg/L
Chloride	> 50 mg/L
Alkalinity	> 300 mg/L

Table 3. Results of nitrogen isotope and nutrient analysis from selected Barton Creek springs.

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