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Effects of low spring discharge on water quality at Barton, Eliza, and Old Mill springs, Austin Texas

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EFFECTS OF LOW SPRING DISCHARGE ON WATER QUALITY AT BARTON, ELIZA, AND OLD MILL SPRINGS, AUSTIN, TEXAS

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Abstract

Water quality in Barton Springs and is associated outlets, Eliza, Old Mill and Upper Barton Springs, declines as flows decline. In addition, storm water impacts as indicated by specific conductance increase as spring flows decrease. During droughts, declining water quality is due to greater percentages of saline water mixing with "normal" Edwards Aquifer waters. Regression formulas allow for predictions of concentrations of specific conductance, nitrate, chloride, sulfate, and sodium that might be expected during severe droughts.

Introduction

The quality of water discharging from Barton Springs, including main Barton, Eliza, Old Mill and Upper Barton Springs, is effected by many factors, including the quality of water in creeks recharging the Edwards Aquifer feeding Barton Springs, the amount of urbanization in upland areas over the recharge zone of the aquifer, rain events in contributing drainages, and the amount of water discharging from the springs which affects leakage from adjacent aquifers. As urbanization expands in the southern areas of the BSEA, demands for water also increase. Water pumped from the Barton Springs Segment of Edwards Aquifer (BSEA) has increased from approximately 0.5 cfs in 1956 to approximately 10.5 cfs in 2003 (BSEACD Management Plan, 2003). Modeling by the Bureau of Economic Geology (Scanlon and others, 2000) and the Barton Springs/Edwards Aquifer Conservation District (Smith and Hunt, 2004) indicates a direct relationship between pumping and spring flows; pumping 10 cfs causes a 10 cfs decline in spring flows. This has raised concerns that pumping during droughts may contribute to drying of Barton Springs when cumulative discharge of the springs dropped as low as 9.6 cfs during the drought of records in the 1950's (USGS, 1990; Smith and Hunt, 2004).

As drought progresses and spring flows drop, there is associated degradation in baseflow water quality of the springs contributed to influx from the saline water zone (Senger and Krietler, 1984; Slade and others, 1986; COA, 1997). In addition, storm water impacts to spring water quality are greater during drought because there is less dilution. Declining water quality during drought may threaten the existence of endangered species dependent on Barton Springs. Understanding how chemical constituents change as spring flows drop is important to protection of the endangered species dependent on spring flow from the aquifer and management of aquifer pumping. During the drought of 1996 cumulative spring discharge dropped to a low of 17 cfs in August and discharge from Eliza and Old Mill outlets was perilously low. This raised concerns that these outlets may dry up completely during a re-occurrence of the drought of record, especially with current levels of pumping from the aquifer.

Methods

Discharge data for Barton Springs is available from the USGS since the late 1880's to present, daily data is available since 1978. The long-term average cumulative discharge from the springs is 53 cfs. Historical chemical data is sparse in the early part of the 1900's but there is a wealth of data beginning in 1978 as the USGS and the City of Austin began a cooperative monitoring program at Barton Springs. Years of data collection over wide ranging flow conditions allows analysis of the impacts of spring discharge on water quality and an estimate the impacts of drought on water quality. A number of common chemical constituents for Barton Springs were examined to quantify their behavior related to flows and predict behavior during severe droughts. Constituents examined include nitrate-nitrogen, specific conductance, turbidity, dissolved oxygen, temperature, and the common ions (calcium, magnesium, sodium, chloride, sulfate, fluoride, and alkalinity). Toxic chemicals and metals were not examined. The data spans from 1922 to 2003. The range in flows with corresponding chemical data is from 12.4 cfs to 130 cfs. Multi-probe data loggers in Barton Springs since 1993 provide a nearly continuous record of temperature, specific conductance, dissolved oxygen, pH, depth, and, since 1994, turbidity. Total dissolved gas was added in 2002. Continuous data provides a much more detailed picture of the gradual and acute impacts from rain events and flows on water quality, a critical component of understanding a karst spring system, missed by traditional grab sampling. Chemical data from the associated springs of Eliza and Old Mill are only available from 1994 to present. Upper Barton Springs is an ephemeral spring, drying up entirely when cumulative spring flows drop below approximately 40 cfs, and so the effects of drought conditions were not examined.

For these analyses, the term "drought" is used to describe periods of low discharge from Barton Springs. Previous analyses of Barton Springs chemistry, (COA, 1997) use arbitrary flow boundaries of 35-40 cfs, 41-64 cfs, and 65-70 cfs to differentiate between low, average, and high flow conditions at the springs. Based on data analyzed for this report, low flow periods and droughts impacting water quality in Barton Springs will include flows at or below 40 cfs.

Linear regression equations derived from drought data were used to predict constituent concentrations below existing data ranges. Water from the saline zone is characterized by chemical data from two saline zone wells (YD 58-50-301, 58-50-902). Barton Springs baseline chemistry is characterized by water discharging from the main spring during average and high flow conditions (greater than 40 cfs). Continuous multiprobe data loggers installed in Main Barton Springs since 1993 are used to examine acute short-term impacts of rain events. Specific conductance in storm water is collected from continuous multiprobe data loggers at Upper Barton Springs during times that they are periodically over whelmed by flooding Barton Creek. Rainfall totals are from COA Flood Early Warning System rain gage records.

Results

The relationship between spring discharge and ion chemistry has been previously documented (Senger and Kreitler, 1984; Slade and others, 1986; COA; 1997). Senger and Krietler and Slade and others illustrated a relationship between spring discharge and sodium and chloride. COA further refined this relationship with other ions, specific conductance and nitrate. Also, a previously unrecognized relationship of nitrate to flow has also been demonstrated (COA 1997; Turner, 2000; Turner and Johns, 2005; Herrington, 2005) although it is less pronounced than with the ions. Most of the major constituents increase as flow decreases, except dissolved oxygen and total suspended solids that decrease as flow decreases.

Data graphs indicate that nutrient and ion concentrations are similar in Barton and Eliza where as most constituent concentrations are greater in Old Mill under all flow conditions. The data indicate that in Barton, Eliza, and Old Mill Springs, changes in water chemistry begin to occur when cumulative spring flows drop below approximately 40 cfs. As illustrated in Figures 1, 2, and 3, there is a pronounced steepening of concentration trends in the springs as flow decreases, especially notable in Old Mill Spring. Regression equations derived from flow and concentration data were used to estimate theoretical concentrations in the springs when spring discharge drops to 5 and 1 cfs. Table 1 shows the equations where "x" is cumulative spring discharge and "y" is the constituent concentration. Data for nitrate included all flow conditions because trends at individual springs are not expressed using only data during low flow conditions.

Figure 1. Sodium concentrations and discharge Barton, Eliza, and Old Mill Springs.

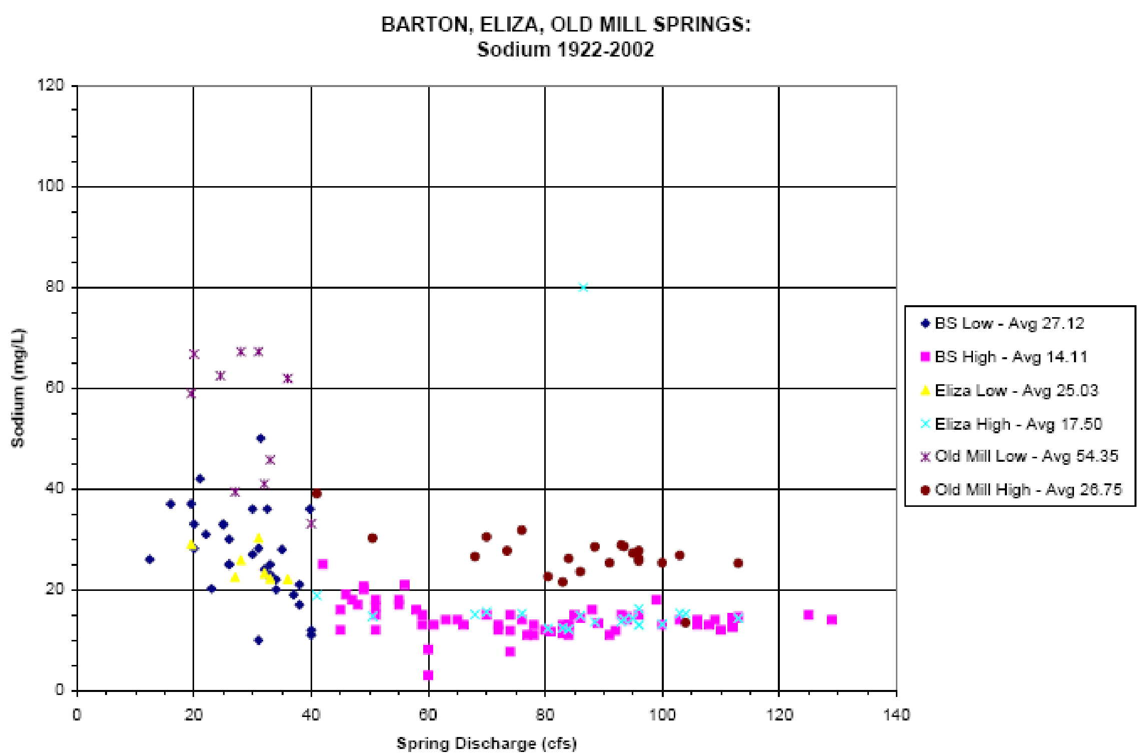


Figure 2. Chloride concentrations and discharge from Barton, Eliza,and Old Mill Springs.

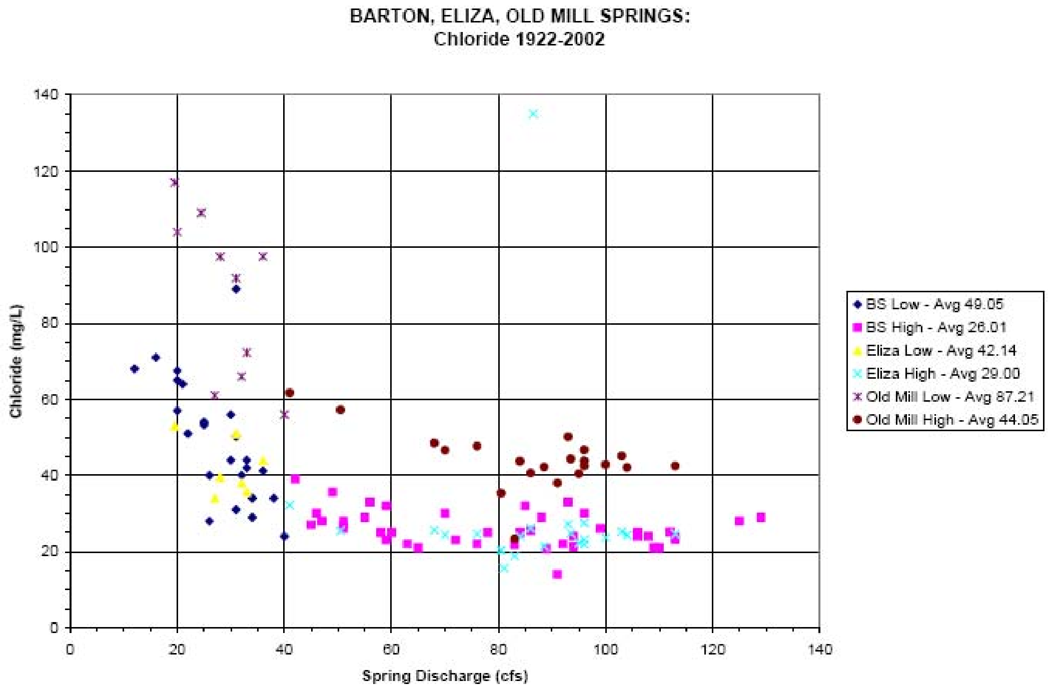


Figure 3. Sulfate concentrations and discharge from Barton, Eliza, and Old Mill Springs.

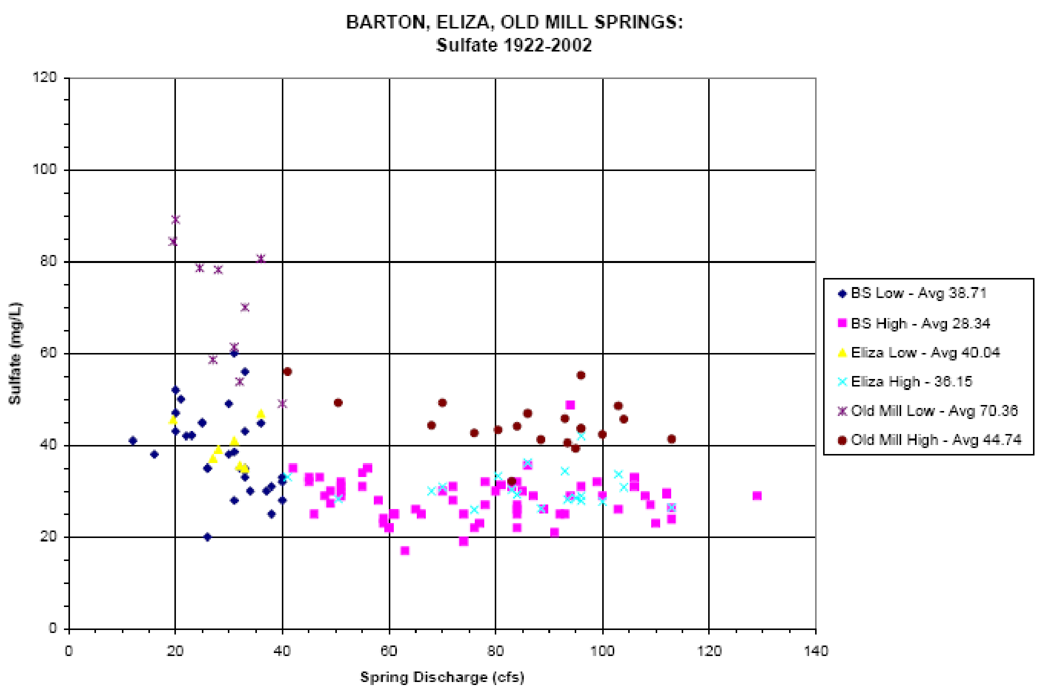


Table 1. Linear regression equations for selected constituents where flow < 40 cfs, except nitrate where all flows are used.

	Old Mill Spring	Barton Spring	Eliza Spring
Sulfate	y = - 1.4032x + 111.19 R^2 = 0.4503	y = - 0.4987x + 53.277 R^2 = 0.1618	y = - 0.1723x + 45.126 R^2 = 0.0381
Chloride	y = - 2.2138x + 151.63 R^2 = 0.4604	y = - 1.4693x + 89.822 R^2 = 0.426	y = - 0.5382x + 58.02 R^2 = 0.1497
Sodium	y = - 1.021x + 84.059 R^2 = 0.265	y = - 0.5541x + 43.302 R^2 = 0.2052	y = - 0.3528x + 35.431 R^2 = 0.3017
Nitrate	y = - 0.0046x + 1.6 R^2 = 0.3507	y = - 0.0031x + 1.5935 R^2 = 0.2494	y = - 0.0019x + 1.3475 R^2 = 0.0679
Specific Conductance	y = - 7.4961x + 1153.6 R^2 = 0.1792	y = - 3.508x + 781.33 R^2 = 0.1978	y = - 3.0777x + 816.16 R^2 = 0.3595
Magnesium	y = - 0.0634x + 27.645 R^2 = 0.0495	y = - 0.3893x + 35.317 R^2 = 0.3908	y = - 0.0865x + 25.88 R^2 = 0.1483
Calcium	y = - 0.0524x + 84.601 R^2 = 0.0033	y = - 0.2525x + 73.967 R^2 = 0.198	y = - 0.0567x + 79.558 R^2 = 0.0037
Fluoride	y = - 0.0069x + 0.5111 R^2 = 0.3924	y = - 0.0072x + 0.5039 R^2 = 0.4983	y = - 0.0037x + 0.3877 R^2 = 0.2104

Table 2 summarizes concentration increases and predicted concentrations at 5 and 1 cfs of combined discharge for several constituents based on the regression equations in Table 1. The greatest changes in major ion concentrations are in chloride, sulfate, sodium, and fluoride. Calcium, magnesium, and alkalinity concentrations change the least. The ratios of calcium to magnesium decrease (slightly lower calcium and higher magnesium) with discharge and is indicative of older water that has been in contact longer with the carbonate host rocks. TSS does not show a well-defined trend with discharge although observations and secchi disk data indicate increasing water clarity with decreasing flows (COA/WPDRD Unpublished data).

Table 2. Average concentrations of selected constituents during normal/high flow and low flow

	Sodium				Chloride			
	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L
Barton Springs	14.11	27.12	40.53	42.75	26.01	49.05	82.48	88.35
Eliza Springs	17.5	25.03	33.67	35.08	29	42.14	55.33	57.48
Old Mill Springs	26.75	54.35	78.95	83.04	44.05	87.21	140.56	149.42

	Sulfate				Nitrite+Nitrate - N			
	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L
Barton Springs	28.34	38.71	50.78	52.78	1.34	1.51	1.59	1.59
Eliza Springs	36.15	40.04	44.27	44.95	1.18	1.33	1.34	1.35
Old Mill Springs	44.74	70.36	104.17	109.79	1.21	1.49	1.58	1.60

	Specific Conductance				Fluoride			
	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L	Normal/High Flow Avg. mg/L	Low Flow Avg. mg/L	5 cfs Est. mg/L	1 cfs Est mg/L
Barton Springs	608	680	764	778	0.19	0.3	0.48	0.50
Eliza Springs	635	723	801	813	0.14	0.27	0.47	0.38
Old Mill Springs	723	941	1116	1146	0.17	0.3	0.37	0.50

Averages based on data from 1922 -2002 except nitrate which is based on data from 1978-2002
Normal and high flows defined as greater than 40 cfs combined discharges from Barton Springs
Low flow defined as less than or equal to 40 cfs combined discharges from Barton Springs
5 cfs average is a linear extrapolation from low flow data except nitrogen
5 cfs average is a linear extrapolation from all data for nitrogen

(drought) and estimated concentrations at 5 and 1 cfs combined discharge from Barton Springs.

Nitrate is a nutrient of particular interest, because it commonly increases in concentration with urbanization and nitrate has recently been documented to increase over time in Barton Springs during low and high flow conditions (Turner, 2000; Herrington, 2005). No trend in nitrate concentration is seen at Barton Springs if only low flow nitrate concentrations are used. Extrapolation of existing trends shows a relatively small increase in nitrate concentrations with decreasing discharge. Predicted concentrations of all constituents at spring discharge rates of 5 and 1 cfs can be misleading, since it assumes there are no additional inputs in the system from over time.

Ten years of continuous data demonstrate the effects of low flow on dissolved oxygen and specific conductance in main Barton Springs. Figure 4 indicates that in 1996 and 2000 when springs flows dropped into the 20-30 cfs range, DO concentrations dropped from “normal” range of approximately 6 mg/L to around 4 mg/L or lower. Low DO during low flows is a critical concern to survival of the species during drought. Similarly, specific conductance during these two periods of low flow increased from around 600-650 uS/cm to around 700-750 uS/cm in the main spring (Figure 5).

Figure 4. Dissolved oxygen and dsicharge from Barton Springs from 1993-2003.

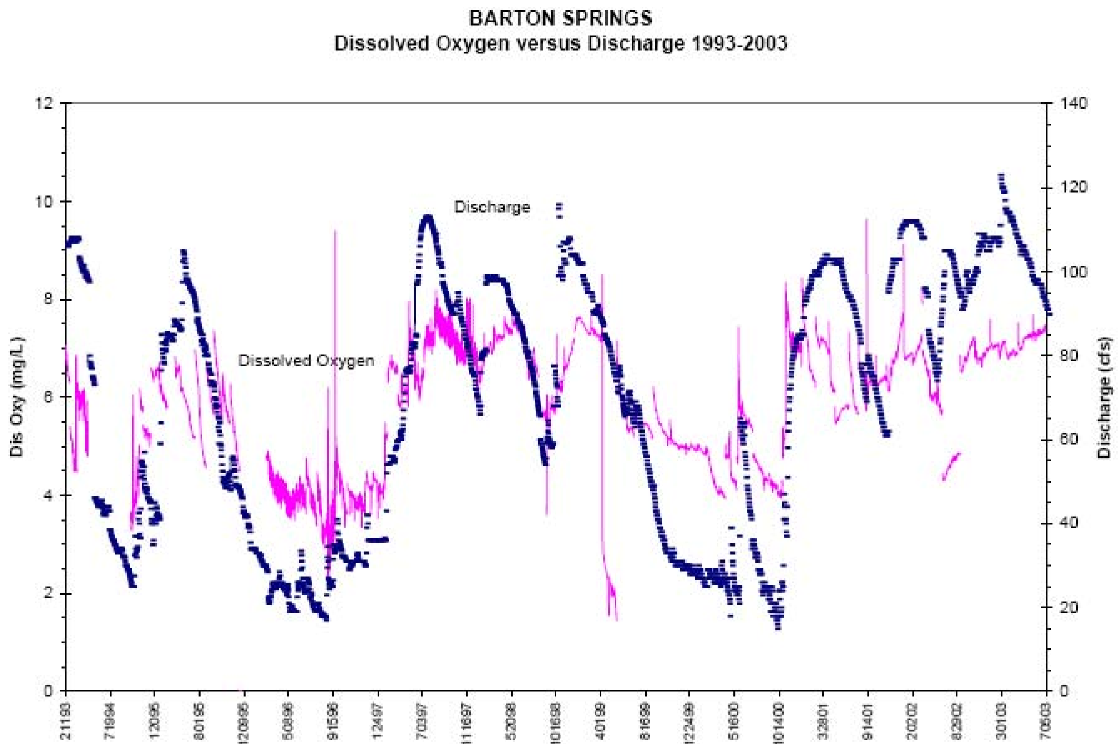
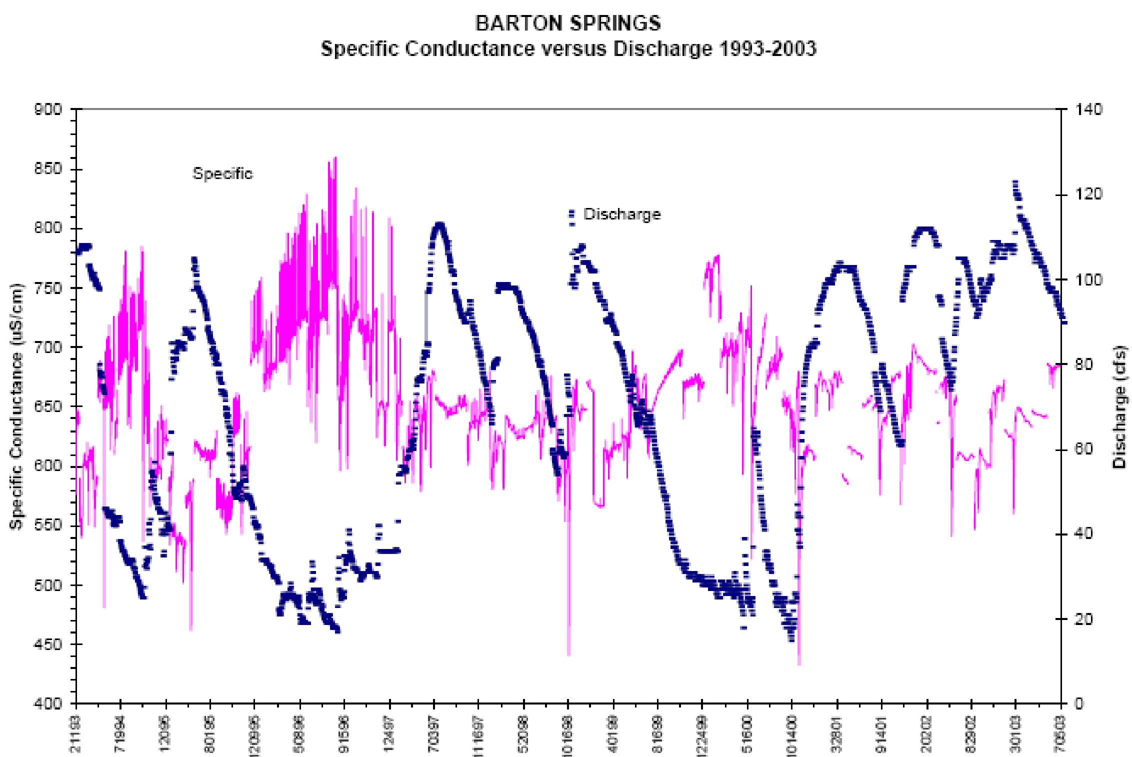


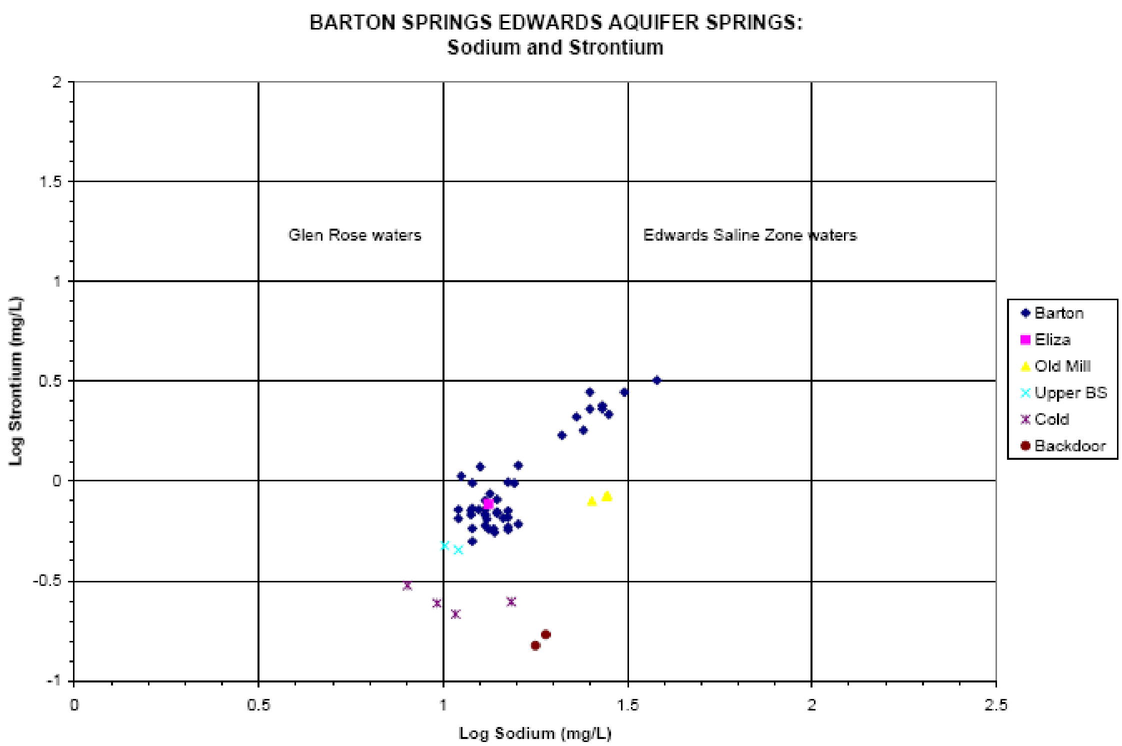
Figure 5. Specific conductance and discharge from Barton Springs from 1993-2003.



Saline Zone Contributions

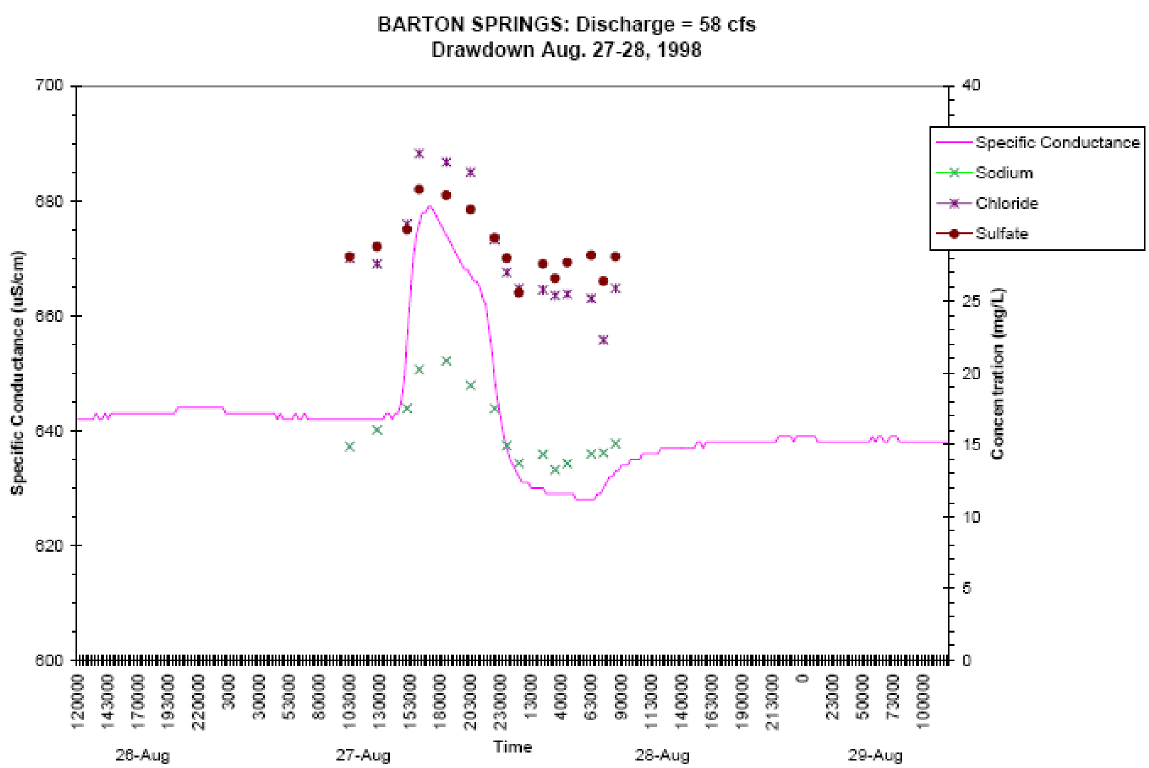
Encroachment of water from the Edwards saline water zone is most likely responsible for the sharp changes in ion chemistry in Barton Springs when discharge drops, although there may also be an unrecognized Trinity water component as well. The saline water zone is defined by concentrations of total dissolved solids greater than 1000 mg/L with equivalent specific conductance values in the range of 14,000 uS/cm. Chloride, sulfate, and sodium concentrations are particularly high in the saline water zone and these three constituents increase the most in spring water during low flows. Figure 6 illustrates the increase in contribution of water from the saline zone to flow for Barton Springs by increasing strontium and sodium content based on relationships established by Senger and Kreitler (1984). Based on a relationship of sulfate to fluoride and fluoride concentrations in Glen Rose wells (COA, 1997), the waters discharging from all the spring outlets do not have a large component of Glen Rose water, they more appear to be Edwards. Any Glen Rose waters entering the Edwards far upgradient may be mixed or equilibrated with the Edwards and therefore indistinguishable. Additional analysis is necessary to determine if the Glen Rose makes significant contributions of water to the Edwards Aquifer.

Figure 6. Sodium and strontium concentrations in Barton Springs Edwards Aquifer springs.



Movement of saline water into the freshwater zone has been documented in the San Antonio area (Groschen,1998). This occurrence is not documented in the BSEA but increases in specific conductance and ion chemistry suggests it is occurring. The spring water chemistry indicates that saline water flows into the freshwater zone during periods of when the water table is low. Drawdowns of Barton Springs Pool (when gates in the lower pool dam are opened to partly drain and lower water levels in the pool) cause a localized drop in the water table (Senger and Kreitler, 1984). A spike in specific conductance of the spring water shortly after drawdown and increasing concentrations of chloride, sulfate, and sodium indicate influx of more saline water (Figure 7). A small drop in specific conductance when the pool is refilled suggests that there is constant contribution of more mineralized water during drawdowns. It is likely that drawdowns mimic lower water table conditions that could be present during drought, especially when considering influx of water from the saline zone. The dropping water levels in Barton Springs Pool locally lowers the water table (Senger and Kreitler, 1984) and the resulting reduction in hydrologic head allows an influx of saline water into the conduits feeding the springs, raising specific conductance and changes ionic composition of spring water. Higher concentrations and higher ratios of calcium to magnesium also indicate that "older" water is discharged during pool drawdowns and droughts as expected if saline water was discharging (water is more saline and has higher calcium/magnesium ratio in the aquifer due to longer periods of contact towards equilibrium with hosting aquifer rocks).

Figure 7. Ion concentrations in Barton Springs during drawdown.



Estimates of the amount of contribution of water from the saline zone during droughts can assist in determining potential impacts to endangered species. Calculations based on simple mixing of water characteristic of the saline zone and Barton Springs average/high flow water were used to match the average and estimated concentrations of constituents from Table 3. This produced an estimate of water discharging from the springs from the saline zone. During low flows (< 40 cfs), saline water making up approximately 0.5% of the water in Barton Springs and approximately

1.75% of the water in Old Mill Spring matches well with average concentrations of sodium, sulfate, chloride, and specific conductance. When flow drops below historical lows, for example to 5 cfs, it is predicted that water from the saline zone will make up approximately 1-to-1.25% and 3-to-3.25% of water in Barton and Old Mill Springs respectively. Although this amounts to only 0.4-to-1.3 gallons per second of saline water, toxicity testing indicates that a solution of approximately 6.25% saline water with a conductivity of approximately 1,100 uS/cm can be fatal to salamanders (COA, 1999).

Table 3. Estimated Water from the Saline Zone in Barton and Old Mill Springs.

		Sodium mg/L	**Sulfate** mg/L	**Chloride** mg/L	**Specific Conductance** uS/cm
Calculated	Saline Average*	2540	2425	3735	14100
Calculated	BS/normal and high flow avg	14.1	28.3	26.0	608
Calculated	BS/low flow avg**	27.1	49.1	38.7	680
Calculated	Old Mill Low flow avg**	54.4	70.4	87.2	941
Estimated	Barton Springs BS/5 cfs***	40.5	50.8	82.5	764
Estimated	Old Mill Springs BS/5 cfs***	79.0	140.6	104.2	1113
Estimated	3.25% saline	102.5	112.2	155.8	1080
Estimated	3% saline	89.9	100.2	137.3	1013
Estimated	2% saline	64.6	76.3	100.2	878
Estimated	1.75% Saline	58.3	70.3	90.9	844
Estimated	1.25% saline	45.7	58.3	72.4	777
Estimated	1% saline	39.4	52.3	63.1	743
Estimated	0.75% saline	33.1	46.3	53.8	709
Estimated	0.5% saline	26.7	40.3	44.6	675

* Average of analyses from wells YD 58-50-301 and YD 58-50-902
** Average from 1922 to 2003 below 40 cfs
*** Estimated based on linear regression from data below 40 cfs

<u>Storm Water Impacts</u>

Multiprobe data loggers measuring physical water quality parameters every 15 minutes in main Barton Springs and other outlets provide a detailed picture of large and small impacts of rain events. Magnitude of these impacts, as measured by changes in specific conductance, vary according to rain volumes and spring flows. Other contributing factors include location and intensity of rain, antecedent moisture, and creek flow conditions although these are not considered here.

Specific conductance of storm water in Barton Creek was used to present recharge water. This data was collected when floods periodically inundated a multiprobe in Upper Barton Springs upstream of Barton Springs Pool. As expected, the data clearly illustrates greater acute impacts from large rain events (Figure 8). However, the data also shows that during low spring flows all rain events have greater impacts on water quality than during average to high spring flows resulting in a greater storm water runoff fraction of spring discharge (Figure 9). For example, at main Barton Springs a one inch rain during average or high spring flows might drop specific conductance around 20 uS/cm whereas the same rain might drop specific conductance by 50 uS/cm during low flows. This indicates that storm water runoff comprises a greater percentage of spring flows. In fact, during low flows storm water can make up over 30% of spring discharge following large rain events (Table 4). Of course, any urban contaminants in the storm water would be in correspondingly higher concentrations as well. Higher concentrations of storm water runoff pollutants on salamanders already potentially stressed from depressed dissolved oxygen and higher salinity could result in significant behavioral and/or physical changes.

Figure 8. Specific conductance and rain during high flows at Barton Springs.

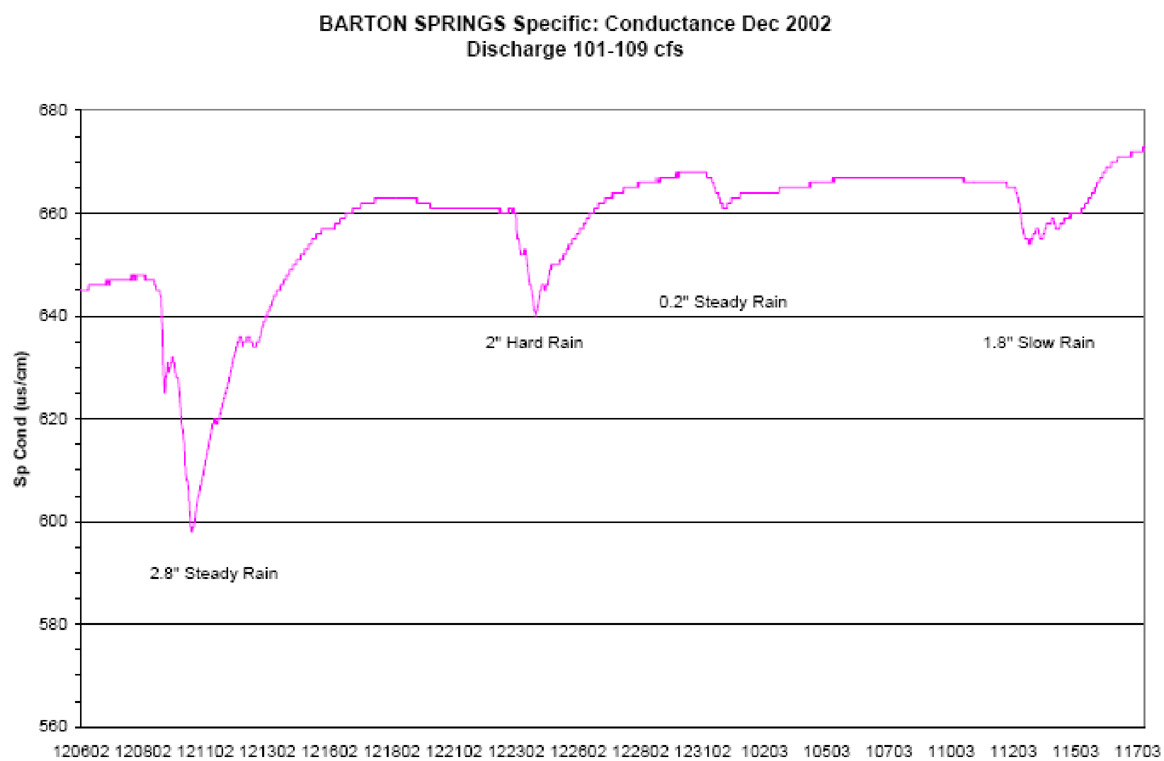


Figure 9. Specific conductance and rain in Barton Springs during high flow conditions.

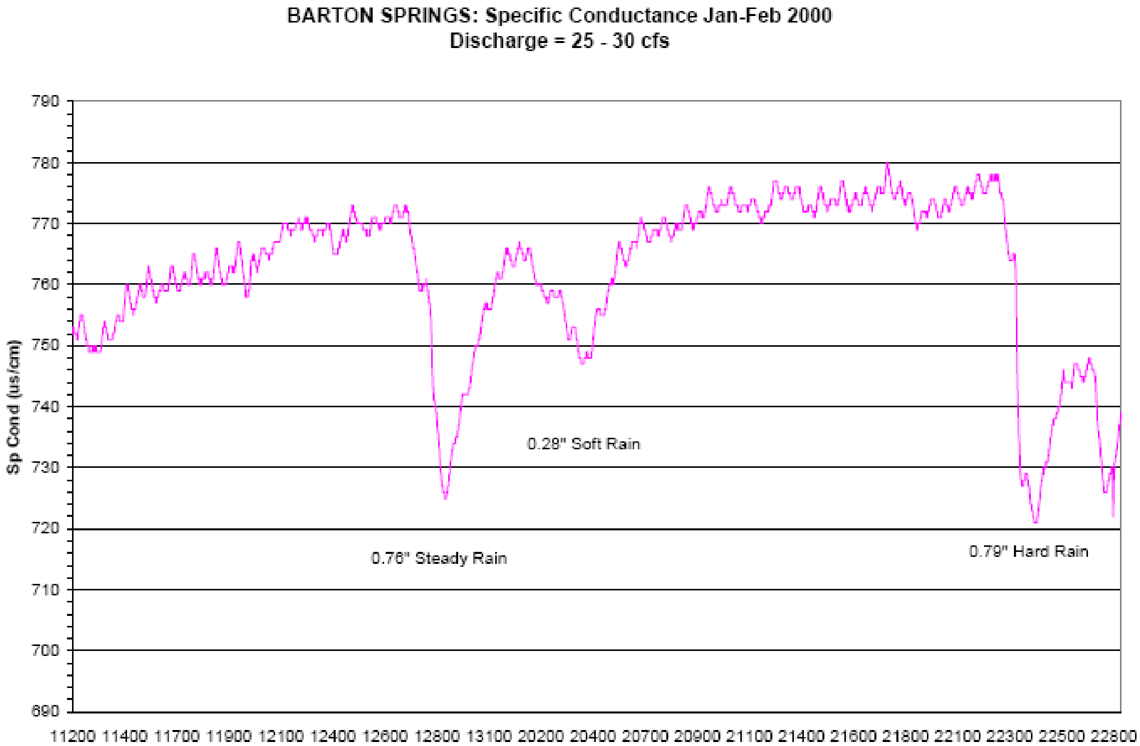


Table 4. Percentage of storm water in Barton Springs and changes in specific conductance.

BARTON SPRINGS LOW FLOWS (<40cfs)		
Change in Specific Conductance	**Stormwater**	**Rain at Loop 360**
uS/cm	Percent	inches
12	2.0%	0.5
35	6.0%	0.7
30	5.0%	0.7
45	7.0%	0.75
55	9.5%	0.8
50	8.5%	1
123	20.5%	1.4
220	35.0%	2.7
BARTON SPRINGS AVG/HIGH FLOWS (>40cfs)		
Change in Specific Conductance	**Stormwater**	**Rain at Loop 360**
uS/cm	Percent	inches
4	0.7%	0.28
2	0.5%	0.44
7	1.5%	0.6
7	1.5%	0.75
15	3.0%	0.8
20	4.0%	0.9
3	0.5%	1.1
10	2.0%	1.25
21	3.5%	1.26
52	9.5%	1.4
18	3.5%	1.4
28	5.0%	1.5
52	9.5%	1.5
24	5.0%	1.5
19	3.5%	1.6
11	2.0%	1.8
67	13.0%	2.2
34	6.0%	2.44
47	9.0%	2.8
58	12.0%	3
74	14.0%	4.6

Regression equations derived from these data where “y” is the percentage of stormwater and “x” is rainfall are:

Barton Springs low flow (<40 cfs): $y = 0.1504x - 0.0439$

Barton Springs average and high flows (>40 cfs): $y = 0.0345x - 0.0025$

Recommendations

There are a number of potential projects to could further investigate water quality impacts associated with low flows at Barton Springs. They include:

- Data indicates that there is a lag between lowering water tables and water quality impacts to the springs. Identifying potential locations of saline water injections into conduits leading to the springs could be explored.
- Since it appears that high water tables impede the influx of saline water to main Barton Springs, staff could experiment with weirs in BS Pool spillways as tool for artificially creating high local water tables and thus reducing impacts of drought on water quality. This technique might also be useful in slowing release of water form the aquifer and therefore serve as a water conservation measure.
- Examine feasibility of other engineered means to augment water quantity and quality during severe droughts to protect salamander species.
- Conduct toxicity testing on salamanders or a surrogate species to determine if predicted concentrations of ions and or saline water during drought threatens endangered species.
- Conduct toxicity testing on salamanders or a surrogate species to determine if predicted percentages of stormwater in springs threatens endangered species.
- Continue analysis of spring water chemistry, including isotopes and trace elements, to identify any Trinity water inflow during droughts or during periodic drawdowns.
- Continue deployment of multiprobe data loggers to collect detailed data from as many spring outlets as feasible.
- Collect additional data, including from multiprobes, salamander population surveys and dissolved gas, from Upper Barton Springs to determine if high concentrations of stormwater in springs flows is related to gas bubble trauma.

Conclusions

Decreasing flows in Barton Springs results in increasing concentrations of most major constituents in spring water accompanied with decreasing levels of dissolved oxygen. Data indicates concentration increases are likely due to increasing contribution of saline zone water to spring flow, making up several percent of spring flow during severe drought. Low spring flow concentrations of constituents generally double over average/high flow concentrations. Regression equations indicate concentrations of many dissolved constituents will triple over average/high flow concentrations at 5 cfs of spring discharge. In addition, stormwater runoff has greater effects on the main Barton Springs during low flows due to less dilution, temporarily making up 30% of spring flow during low spring flows and following large rain events.

It is currently unknown if these conditions will threaten the survival of the endangered salamanders. Predicted concentrations are less than concentrations that caused total mortality in a toxicity test of related salamander species. However, there is currently insufficient data from those toxicity tests to determine if these predicted concentrations pose a threat to the species.

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