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Temporal Trend Analysis of Long-term Monitoring Data at Karst Springs, 2009

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Water quality is degrading over time at Main Barton Springs, Austin, Texas, as determined by multiple linear regression analyses (COA 2005). Similar techniques are applied to long-term monitoring data from 5 other Barton-related springs: Upper Barton Springs, Old Mill Springs, Eliza Springs, Backdoor Springs and Cold Springs. Categorical variables representing low-flow condition, laboratory method, filter fraction and analytical method were also used in the regression analysis. Varying temporal trends were observed at study springs. Due to variations in contributing watersheds, local influences, and aquifer mixing, observed temporal trends at other Barton complex springs did not always match observed trends at Main Barton Springs noted in previous analyses.

Introduction

The City of Austin (COA) in cooperation with the United States Geological Survey (USGS) have conducted long-term water quality monitoring of several karst springs in the Austin area. Previous COA analyses (COA 2005, COA 2000) have demonstrated the utility of multiple linear regression analyses to incorporate data collected by multiple agencies or using different laboratory methods to document long-term changes in water quality. Previous analysis has shown that water quality is degrading over time at the main Barton Springs. Temporal trends at main Barton Springs and five related springs (Upper Barton, Old Mill/Sunken Garden, Eliza, Backdoor, and Cold Springs) are assessed by similar methods in this report. Additionally, temporal trends in chlorophyll-a measured in Barton Springs Pool at the downstream dam are assessed.

Methods

Sample collection entities include the City of Austin Water Resource Evaluation Section (WRE), the Austin/Travis County Health and Human Services Department and the US Geological Survey (USGS). All data included in the analyses are stored in the City of Austin Field Sampling Database (FSDB) and are available upon request. Data collected specifically by WRE is available at www.ci.austin.tx.us/wrequery/, and data collected by the USGS is available at waterdata.usgs.gov/tx/nwis. These agencies represent the most comprehensive resources in terms of both number of samples and period of record for these springs.

Data from main Barton Springs and five related karst springs (Table 1) are assessed. Chlorophyll-a data from Barton Springs Pool measured at the downstream dam are assessed.

High Barton Springs was initially considered but did not have sufficient period of record to be included. The general period of record for data assessed in this report is the mid-1990s to the summer of 2009, although the period of record for main Barton Springs is much longer with earliest water quality measurements in the 1960s.

Approximately 565 parameters from the five study sites were excluded from the analysis because data did not satisfy sample size or period of record requirements or did not have a sufficient number of measurements above detection limits. There were 52 parameters included in the subsequent analysis. Parameters were analyzed for temporal trends only if:

- Data are available after 2005 (recent data)
- Data are available before 2007 (at least 2 years of data)
- There are at least 5 measurements (sufficient number of measurements)
- There are at least 2 detected measurements (some measurements above detection limits).

Table 1. Study spring locations with latitude/longitude and site abbreviations used in the report.

COA #	Spring Name	Abbreviation	Latitude	Longitude
160	Backdoor Spring	BKDR	30.25951	-97.82370
183	Upper Barton Spring	UBS	30.26359	-97.77378
422	Old Mill (Sunken Gardens) Spring	OM	30.26359	-97.76808
428	Eliza Spring	ES	30.26425	-97.77006
9	Cold Springs	CS	30.27963	-97.78050
35	Main Barton Springs	MBS	30.26356	-97.77128

Parameters normally measured in the field (conductivity, dissolved oxygen, pH, turbidity and water temperature) that were measured in the laboratory were excluded from the analysis (except for USGS conductivity measurements analyzed in the lab). These data were excluded in previous analyses at Main Barton Springs as well (COA 2005). All outliers as determined from visual inspection of the graphs by site and parameter were examined individually. Invalid data were removed prior to analysis when a valid rationale for error, such as laboratory quality control or sampling equipment failure, was documented by project personnel in comments associated with database records.

Samples affected by Barton Springs Pool drawdown for maintenance were excluded from the analysis, as pool drawdown results in temporarily increased conductivity and turbidity and decreased dissolved oxygen (COA 2000) by drawing in water from the saline water zone. Drawdown sample dates excluded from the analysis are: August 13, 1998; August 27-28, 1998; September 17-18, 1998.

Differences in water quality at main Barton Springs have been documented based on categorizing the data with respect to surface water recharge input to the aquifer from flowing creeks. During recharge conditions, Barton Springs water quality is reflective of the current water quality of creeks within the recharge zone (COA 1997; COA 2000). During non-recharge conditions, Barton Springs discharge is primarily a reflection of long-term water quality of the aquifer (COA 2000). Recharge condition was determined using mean daily flow at the Barton Creek at Loop 360 USGS gage (USGS 08155300, available at waterdata.usgs.gov/tx/nwis). Dates with non-zero mean daily flow at the gage were classified as “recharge” while dates with zero mean daily flow at the gage were classified as “non-recharge” conditions.

Previous dye tracing studies have shown that the areas contributing to Cold Springs include the Eanes Creek watershed, the channel and uplands of Barton Creek between Loop 360 and Lost Creek Boulevard as well as Williamson Creek between US 290 and Brush County Boulevard. This data indicates that creek recharge conditions for Cold Springs may be more appropriately determined by use of the USGS gauge on Barton Creek at Lost Creek Boulevard (USGS 08155240) upstream of the Cold Spring contributing area, rather than Loop 360 on the downstream end of the contributing area to Cold Springs. There is no visual difference in the relationship of conductivity to flow at the two gauges (Figure 1), and there is no statistically significant correlation (Kendall's tau- β) between Cold Springs conductivity and flow at either gauge. The Lost Creek gauge did not yield any days with no flow when Cold Springs was sampled, and thus to be used in this analysis some minimum flow rate would need to be determined to accurately separate "high" and "low" recharge conditions for Cold Springs. For consistency, recharge condition for Cold Springs was determined by Loop 360 flows as done for the other sites. If there is no relation between any parameter and recharge condition at Cold Springs, the method of backward elimination will simply remove recharge condition from the model. Backward elimination regression models start with all candidate variables in the regression equation, and then eliminate non-significant variables programmatically until only the most parsimonious set of significant variables remain.

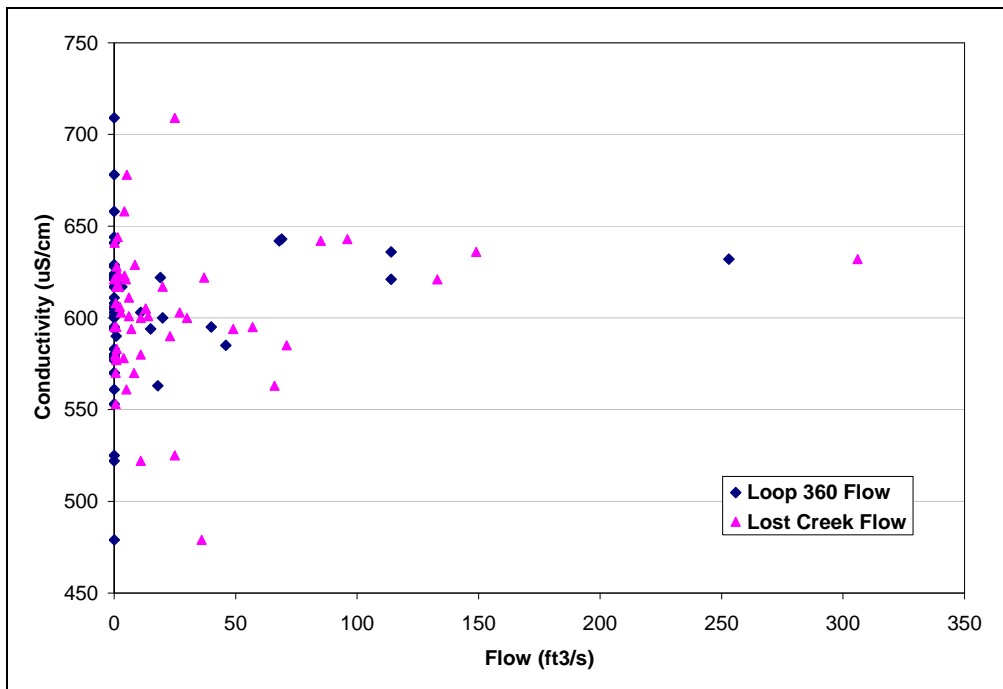


Figure 1. Conductivity at Cold Springs versus daily average flow from USGS gauges on Barton Creek at Loop 360 and Lost Creek Boulevard.

Storm-influenced samples were excluded from the analysis. Storm designation was determined by examination of bacteria or total suspended solids (TSS) results from Main Barton Springs for each sample date. Antecedent rainfall at the National Weather Service Camp Mabry gauge was used in combination with the mean daily flow at Barton Springs as recorded by the USGS and an examination of water quality data and field staff notes to determine if samples were storm-influenced.

Some water quality parameters in Barton Springs are strongly correlated with spring discharge (Senger and Kreitler 1984, COA 1997, COA 2000). Barton Springs mean daily discharge was entered into the multiple linear regression equations before the sample collection date to account for variation in concentration with discharge in temporal trend analyses, as in previous City of Austin analyses (COA 2000, COA 2005). Non-linear relationships with discharge have been observed for multiple dissolved solids parameters (chloride, sulfate, sodium, potassium, strontium, TDS and conductivity) at low discharge values (COA 2005, 2006). An overall average critical low flow value of 38 ft³/s was used for these 7 parameters (as the low-flow variable) in the temporal regression equations, following the approach previously used based on an identified breakpoint in sample result versus spring discharge regressions (COA 2005). This improves prediction accuracy by removing the non-linearity of the discharge coefficient for these parameters, enables prediction of change in values at both very low discharge and at long-term average discharge and follows the methods used to previously assess Main Barton Springs temporal trends.

Multiple linear regression was used to determine if parameter results were changing over time, the direction of the change and the statistical significance of the change, following the methodology of previous studies (COA 2000, COA 2005). Analysis groups (non-recharge, recharge) were analyzed together and accounted for in the model with a recharge group variable. Mean daily flow at Barton Springs as determined by the USGS gauge (08155500) was associated with every sample collection date. The “low-flow” variable was included for the parameters with non-linear relationships to flow (COA 2005). Categorical method/collector variables were entered into the regression equation, followed by Barton Springs flow and then date. A backward elimination model was used in PROC REG (SAS 2004) to eliminate non-significant regression coefficients from the model. The full model is thus:

$$\text{Concentration} = (\text{Collector or Method or Filter}) + (\text{Collector or Method or Filter} * \text{date}) + (\text{recharge condition}) + (\text{low-flow}) + (\text{discharge}) + (\text{date})$$

Multiple linear regression results for parameters with censored observations (non-detect) were confirmed using the semi-parametric Cox proportional hazards regression (Allison 1995). Scatter plots of data were examined for all parameters to assess the validity of the analytically-determined trends. Values were normalized to 50 ft³/s prior to plotting to remove flow effects for models with a statistically significant flow relation.

Observed trends are compared to previous results from Main Barton Springs (COA 2005). Parameters or conditions with no statistically significant ($\alpha \leq 0.05$) trends over time are not presented. Date values in SAS are represented as a Julian date, calculated as the number of days from the date 1 January 1960.

Results

Although there were sufficient data for analysis, no significant temporal trends were evident for 32 parameters at any assessed site (Table 2). Similarly, no trends were observed for these same parameters in the 2005 analysis at main Barton Springs (COA 2005). There was also no temporal trend in color, measured by the USGS in Pt-Co units, at main Barton Springs. Color was not previously assessed in main Barton Springs in 2005, and insufficient data for color was available at the other sampling locations.

Previously reported increasing trends in iron, lead and zinc (COA 2005) at main Barton Springs have been confirmed as lab error relating to the acid preservation of sample bottles. After removing compromised sample results, there are no statistically significant trends in iron, lead or

zinc at any site, although high iron values have been detected in recent samples at Old Mill Springs. A method change in 2006 for nickel from EPA 200.7 to EPA 200.8 visually yields a false temporal trend, although PHREG analysis accounting for both change in method and measurements less than detection limits yields no statistically significant nickel trends over time at any site.

Table 2. Parameters without significant temporal trends at any site assessed.

Parameter
Aluminum
Ammonia
Arsenic
Atrazine
Bis(2-ethylhexyl) phthalate
Boron
Bromide
Cadmium
Caffeine
Carbayl (Sevin)
Chloroform
Chlorophyll-a*
Chromium
Copper
Diazinon
E. coli bacteria
Iron
Lead
Manganese
Nickel
Oil and Grease
Organic Carbon
Orthophosphorus
Phosphorus
Potassium
Silver
Simazine
Tetrachloroethylene
Total Suspended Solids
Turbidity
Volatile Suspended Solids
Zinc

*assessed at downstream dam in Barton Springs Pool only, insufficient data for trend assessment at other sites.

Temporal trend results are presented in tabular format showing the estimated coefficient value for the variable in the regression equation (Estimate), the standard error associated with that estimate (StdErr) and the significance of the variable estimate ($Pr > F$). Only significant (" $Pr > F$ " values less than 0.05) variables remaining after backward elimination are shown in the tables. Positive values for the "date" estimate coefficient indicate significant, increasing temporal trends while negative values for the "date" estimate indicate significant, decreasing temporal trends.

Alkalinity

The USGS generally measures dissolved alkalinity as CaCO_3 (mg/L) in the field. COA measures total alkalinity in the lab (Table 3). Categorical variables were used to represent collecting entities, filter fractions and laboratories.

Table 3. Alkalinity data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	4	2005	2007
Dissolved	USGS	ES	52	2003	2006
Dissolved	USGS	MBS	140	1990	2009
Dissolved	USGS	OM	47	2003	2005
Dissolved	USGS	UBS	46	2003	2005
Total	ATCHD	MBS	95	1992	1993
Total	USGS	MBS	36	1978	1992
Total	WRE	BKDR	49	1995	2009
Total	WRE	CS	55	1994	2009
Total	WRE	ES	89	1995	2009
Total	WRE	MBS	143	1991	2009
Total	WRE	OM	98	1994	2009
Total	WRE	UBS	81	1997	2008

Prior to backward elimination, the full model for alkalinity is:

$$\text{Alkalinity} = \text{filter} + \text{filter}*\text{date} + \text{collector} + \text{collector}*\text{date} + \text{lab} + \text{lab}*\text{date} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Alkalinity yields an increasing temporal trend only in main Barton Springs (Table 4), with no other temporal trends evident at other sites. Alkalinity was previously found to be increasing during recharge only conditions. This analysis accounts for recharge conditions as a variable in the model, and thus predicted temporal trends are assessed for both recharge and non-recharge conditions combined and not separately as previously done. Increased variability in alkalinity measurements was observed in 2004-2005 at Eliza, Old Mill and Upper Barton Springs. Alkalinity appeared to be increasing at Backdoor Springs thru 2000, but appears to have stabilized since that time.

Table 4. Alkalinity as CaCO_3 (mg/L) results.

Site	adj r2	Type	Estimate	StdErr	Pr>F
BKDR	0.31	Intercept	189.189	35.717	0.0000
		filter	.	.	.
		filter*date	0.010	0.002	0.0000
		collector	.	.	.
		coll*date	-0.001	0.001	0.0916
		lab	.	.	.
		lab*date	.	.	.
		recharge	.	.	.
		bs_flow	.	.	.
		date	.	.	.

Table 4 (continued)

Site	adj r2	Type	Estimate	StdErr	Pr>F
CS	0.25	Intercept	240.765	3.904	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		coll*date	.	.	.
		lab	.	.	.
		lab*date	.	.	.
		recharge	20.402	4.737	0.0001
		bs_flow	.	.	.
		date	.	.	.
ES	0.51	Intercept	8609.615	2897.590	0.0037
		filter	-6983.457	2413.266	0.0047
		filter*date	-0.040	0.013	0.0040
		collector	.	.	.
		coll*date	0.048	0.016	0.0034
		lab	-837.791	206.803	0.0001
		lab*date	0.052	0.013	0.0001
		recharge	12.249	2.876	0.0000
		bs_flow	0.307	0.051	0.0000
		date	.	.	.
MBS	0.27	Intercept	254.874	8.414	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	-56.096	8.193	0.0000
		coll*date	0.005	0.001	0.0000
		lab	12.929	2.775	0.0000
		lab*date	.	.	.
		recharge	11.576	2.204	0.0000
		bs_flow	0.164	0.040	0.0001
		date	-0.001	0.001	0.0254
OM	0.26	Intercept	217.834	9.029	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		coll*date	0.001	0.000	0.0038
		lab	-443.673	172.630	0.0117
		lab*date	0.028	0.011	0.0097
		recharge	16.707	4.146	0.0001
		bs_flow	0.303	0.074	0.0001
		date	.	.	.

Table 4 (continued)

Site	adj r2	Type	Estimate	StdErr	Pr>F
UBS	0.43	Intercept	16733.624	5164.694	0.0018
		filter	13779.622	4303.063	0.0020
		filter*date	-0.075	0.024	0.0026
		collector	.	.	.
		coll*date	0.094	0.029	0.0016
		lab	-1123.044	342.600	0.0016
		lab*date	0.070	0.021	0.0013
		recharge	.	.	.
		bs_flow	0.288	0.139	0.0420
UBS	0.43	date	.	.	.

Barium, Dissolved

The majority of available barium data is dissolved (Table 5), collected by the USGS and can be assessed only at main Barton Springs. Two suspect values at MBS from the early 1980s were excluded from the analysis as probable outliers.

Table 5. Barium data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	1	2005	2005
Dissolved	USGS	MBS	74	1978	2009
Dissolved	USGS	OM	1	2005	2005
Dissolved	USGS	UBS	1	2002	2002
Dissolved	WRE	CS	1	1994	1994
Dissolved	WRE	OM	1	1994	1994
Total	WRE	BKDR	2	1995	1995
Total	WRE	CS	2	1995	1995
Total	WRE	MBS	5	1994	1995
Total	WRE	OM	2	1995	1995

Prior to backward elimination, the full model for Barium was:

$$Ba, diss = recharge_group + bs_flow + date$$

Dissolved barium is increasing over time in MBS (Table 6). Early total barium concentrations at Backdoor Spring in 1995 were lower than current dissolved values (2005-2007), but there is insufficient data for complete assessment. Despite the increasing trend in barium, all measurements in main Barton Springs are less than 70 µg/L and the estimated lowest observed effect concentration for aquatic organisms is approximately 5,800 µg/L (Texas Surface Water Quality Standards, 30 TAC Chapter 307).

Table 6. Dissolved Barium (µg/L) results.

Site	Adj r2	Type	Estimate	Std Error	Pr>F
MBS	0.69	intercept	48.981	3.831	0.0000
		recharge group	3.952	2.077	0.0655
		bs_flow	-0.141	0.033	0.0002
		date	0.001	0.000	0.0004

Calcium

The USGS measures dissolved calcium, while COA has measured both total and dissolved (Table 7). Current COA samples typically measure only total calcium. A categorical variable was added to account for differences in filter fraction.

Prior to backward elimination, the full model for calcium was:

$$\text{Calcium} = \text{filter} + \text{filter} * \text{date} + \text{flow_group} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Table 7. Calcium data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	51	2003	2006
Dissolved	USGS	MBS	138	1978	2009
Dissolved	USGS	OM	48	2003	2005
Dissolved	USGS	UBS	48	2002	2005
Dissolved	WRE	BKDR	1	2000	2000
Dissolved	WRE	CS	2	1994	2000
Dissolved	WRE	ES	1	2000	2000
Dissolved	WRE	MBS	1	2000	2000
Dissolved	WRE	OM	3	1994	2000
Total	WRE	BKDR	52	1995	2009
Total	WRE	CS	55	1995	2009
Total	WRE	ES	63	1995	2009
Total	WRE	MBS	93	1991	2009
Total	WRE	OM	70	1995	2009
Total	WRE	UBS	44	1997	2008

Combining dissolved and total calcium in the same regression model yields only an increasing temporal trend at main Barton Springs. Analyzing dissolved calcium separately yields increasing trends only at main Barton Springs. Analyzing total calcium separately yields increasing trends at all sites (Table 8).

Table 8. Calcium (mg/L) results.

Site	adj r ²	Type	Estimate	Std Err	Pr>F
BKDR	0.53	intercept	138.427	52.437	0.0112
		filter	-103.679	42.922	0.0196
		filter*date	0.005	0.001	0.0000
		flow group	.	.	.
		recharge	.	.	.
		bs_flow	0.099	0.041	0.0194
		date	.	.	.
CS	0.46	intercept	131.632	30.840	0.0001
		filter	-89.829	26.779	0.0016
		filter*date	0.002	0.000	0.0000
		flow group	-5.567	3.010	0.0707
		recharge	7.411	2.888	0.0135
		bs_flow	0.174	0.064	0.0089
		date	.	.	.
ES	0.38	intercept	85.084	14.618	0.0000
		filter	-28.608	12.194	0.0213
		filter*date	0.002	0.000	0.0000
		flow group	.	.	.
		recharge	.	.	.
		bs_flow	0.119	0.019	0.0000
		date	.	.	.
MBS	0.44	intercept	242.692	72.600	0.0011
		filter	-156.896	65.218	0.0175
		filter*date	0.010	0.004	0.0210
		flow group	.	.	.
		recharge	.	.	.
		bs_flow	0.099	0.013	0.0000
		date	-0.010	0.005	0.0348
OM	0.42	intercept	121.438	17.706	0.0000
		filter	-59.686	15.142	0.0002
		filter*date	0.002	0.000	0.0000
		flow group	-11.901	2.607	0.0000
		recharge	.	.	.
		bs_flow	0.071	0.036	0.0556
		date	.	.	.
UBS	0.37	intercept	88.455	17.842	0.0000
		filter	-39.408	14.766	0.0103
		filter*date	0.003	0.001	0.0001
		flow group	.	.	.
		recharge	-4.599	1.422	0.0022
		bs_flow	.	.	.
		date	.	.	.

Chloride

The USGS currently measures dissolved chloride, while COA measures total chloride (Table 9). A categorical variable (0=total, 1=dissolved) was used to represent the filter types. Although included in all models in the initial list of candidate variables, the non-linear relationship between

chloride and Main Barton Springs flow at low flows near 40 ft³/s was only evident in scatter plots of chloride versus flow at Old Mill and Eliza but not Cold, Upper Barton or Backdoor springs..

Table 9. Chloride data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	20	2005	2006
Dissolved	USGS	MBS	35	2005	2009
Dissolved	USGS	OM	16	2005	2005
Dissolved	USGS	UBS	16	2005	2005
Total	ATCHD	MBS	43	1991	1991
Total	USGS	ES	31	2003	2004
Total	USGS	MBS	105	1978	2004
Total	USGS	OM	32	2003	2004
Total	USGS	UBS	30	2003	2004
Total	WRE	BKDR	51	1995	2009
Total	WRE	CS	57	1994	2009
Total	WRE	ES	64	1995	2009
Total	WRE	MBS	96	1991	2009
Total	WRE	OM	71	1994	2009
Total	WRE	UBS	45	1997	2008

Prior to backward elimination, the full model for chloride was:

$$\text{Chloride} = \text{filter} + \text{filter} * \text{date} + \text{collector} + \text{collector} * \text{date} + \text{flow_group} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Increasing trends in chloride over time were observed at Backdoor Springs and Eliza Springs, with a decreasing trend observed in Upper Barton Springs. Although increasing in 2005 results, chloride yields a weak decreasing trend in main Barton Springs (Table 10). When total and dissolved chloride are analyzed separately at main Barton Springs, a weak decreasing temporal trend is observed for total chloride (1978-2009) while an increasing trend is observed for dissolved chloride (2005-2009).

Table 10. Chloride (mg/L) results.

Site	adj r ²	Type	Estimate	Std Err	Pr>F
BKDR	0.29	intercept	10.440	6.036	0.0904
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		coll*date	.	.	.
		flow_group	7.219	2.108	0.0013
		recharge	.	.	.
		bs_flow	-0.086	0.033	0.0110
		date	0.001	0.000	0.0032
CS	0.50	intercept	6410.694	1975.431	0.0021
		filter	5344.789	1646.357	0.0021
		filter*date	0.030	0.009	0.0015
		collector	.	.	.
		coll*date	-0.035	0.011	0.0020
		flow_group	6.698	1.135	0.0000
		recharge	.	.	.
		bs_flow	.	.	.
		date	.	.	.
ES	0.82	intercept	3211.324	1447.575	0.0294
		filter	2914.291	1251.789	0.0225
		filter*date	-0.180	0.076	0.0206
		collector	-249.692	83.683	0.0038
		coll*date	0.016	0.005	0.0034
		flow_group	-11.569	1.703	0.0000
		recharge	.	.	.
		bs_flow	-0.084	0.025	0.0010
		date	0.201	0.088	0.0250
MBS	0.72	intercept	50.336	2.077	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		coll*date	.	.	.
		flow_group	-12.365	1.469	0.0000
		recharge	.	.	.
		bs_flow	-0.094	0.021	0.0000
		date	-0.0004	0.000	0.0080

Table 10 (continued)

Site	adj r2	Type	Estimate	Std Err	Pr>F
OM	0.63	intercept	109.087	5.364	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		coll*date	.	.	.
		flow_group	-46.781	8.433	0.0000
		recharge	.	.	.
		bs_flow	-0.211	0.115	0.0719
		date	.	.	.
UBS	0.13	intercept	9.471	10.128	0.3544
		filter	.	.	.
		filter*date	0.002	0.001	0.0313
		collector	.	.	.
		coll*date	.	.	.
		flow_group	.	.	.
		recharge	2.313	1.259	0.0725
		bs_flow	0.132	0.043	0.0034
		date	-0.003	0.001	0.0142

Conductivity

Conductivity is measured by multiple different field instruments (Table 11). A categorical variable was used to represent the different field instruments.

Prior to backward elimination, the full model for instantaneous conductivity was:

$$\text{Inst. Conductivity} = \text{method} + \text{method} * \text{date} + \text{flow_group} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Table 11. Instantaneous conductivity data with field instrument.

Collector	Site	Method	#	First	Last
USGS	ES	UNKNOWN	16	2004	2004
USGS	MBS	UNKNOWN	23	1980	2005
USGS	OM	UNKNOWN	17	2004	2004
USGS	UBS	UNKNOWN	16	2004	2004
WRE	BKDR	HORIBA WATER QUALITY METER	20	1995	2001
WRE	BKDR	HYDROLAB	1	2002	2002
WRE	BKDR	Quanta Probe	40	2002	2009
WRE	CS	CORNING M90	1	1995	1995
WRE	CS	HORIBA WATER QUALITY METER	20	1995	2001
WRE	CS	HYDROLAB	11	1991	2002
WRE	CS	Quanta Probe	22	2002	2009
WRE	ES	HORIBA WATER QUALITY METER	21	1995	2001
WRE	ES	HYDROLAB	2	2002	2006
WRE	ES	Quanta Probe	64	2002	2009
WRE	MBS	COLE PARMER FIELD STICK	1	2001	2001
WRE	MBS	COLE PARMER PHCON10	1	2001	2001
WRE	MBS	HORIBA WATER QUALITY METER	164	1995	2001
WRE	MBS	HYDROLAB	13	2001	2004
WRE	MBS	Quanta Probe	147	2000	2009
WRE	MBS	UNKNOWN	1	1995	1995
WRE	MBS	YSI Probe	1	2000	2000
WRE	OM	HORIBA WATER QUALITY METER	29	1995	2001
WRE	OM	HYDROLAB	2	2002	2006
WRE	OM	Quanta Probe	31	2002	2009
WRE	UBS	HORIBA WATER QUALITY METER	23	1997	2001
WRE	UBS	HYDROLAB	3	2002	2002
WRE	UBS	Quanta Probe	14	2002	2008

Over the period of record, instantaneous conductivity appears to be increasing at Backdoor Springs and Cold Springs, but decreasing at main Barton Springs, Old Mill Springs and Eliza Springs (Table 12). The decrease at main Barton Springs is observed in both recharge and non-recharge conditions, and was previously (COA 2005) found to be increasing only in recharge conditions. When only the most recent COA field instrument is assessed (the Quanta probe, in use from 2000 to present), no trend is evident at main Barton Springs.

Table 12. Instantaneous conductivity ($\mu\text{S}/\text{cm}$) results.

Site	adj r ²	Type	Estimate	Std Err	Pr>F
BKDR	0.43	intercept	-360.059	357.708	0.32
		flow_group	.	.	.
		method	463.091	138.309	0.00
		method*date	-0.029	0.009	0.00
		recharge_group	35.587	14.452	0.02
		bs_flow	.	.	.
		date	0.072	0.025	0.01
CS	0.32	intercept	426.024	41.973	0.00
		flow_group	.	.	.
		method	.	.	.
		method*date	.	.	.
		recharge_group	34.511	12.994	0.01
		bs_flow	0.761	0.189	0.00
		date	0.007	0.002	0.01
ES	0.73	intercept	1100.540	93.581	0.00
		flow_group	-45.477	6.687	0.00
		method	-159.542	51.745	0.00
		method*date	0.011	0.003	0.00
		recharge_group	15.764	6.611	0.02
		bs_flow	.	.	.
		date	-0.030	0.006	0.00
MBS	0.46	intercept	752.365	26.225	0.00
		flow_group	-53.744	4.582	0.00
		method	17.910	2.673	0.00
		method*date	.	.	.
		recharge_group	12.074	4.435	0.01
		bs_flow	.	.	.
		date	-0.007	0.002	0.00
OM	0.73	intercept	1633.875	295.134	0.00
		flow_group	-219.481	23.976	0.00
		method	-399.456	181.257	0.03
		method*date	0.026	0.011	0.02
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	-0.048	0.019	0.02
UBS	0.48	intercept	511.647	31.986	0.00
		flow_group	.	.	.
		method	.	.	.
		method*date	0.001	0.000	0.00
		recharge_group	.	.	.
		bs_flow	0.928	0.365	0.02
		Date	.	.	.

The main Barton Springs daily average conductivity relationship with flow yielded an unexpected change during the recent drought from the previous pattern established since the installation of the continuous monitoring probe in 2003 (Figure 2). In July 2008, main Barton Springs discharge fell below 28 ft³/s. Conductivity measurements from the recent drought from July 2008 thru early

August 2009 (when flows were in the 17 ft³/s range) deviated from the previously established pattern by plotting generally slightly lower than during previous periods of flow less than 30 ft³/s. The recent drought measurements result in a statistically significant ($Pr > |t| = 0.0001$) reduction ($0.5 \mu\text{S}\cdot\text{cm}^{-1}/\text{ft}^3\cdot\text{s}$) in the predicted change of daily average conductivity slope versus daily average Barton Springs discharge at flows less than 38 ft³/s despite a sharp increase in conductivity at flows less than 18 ft³/s.

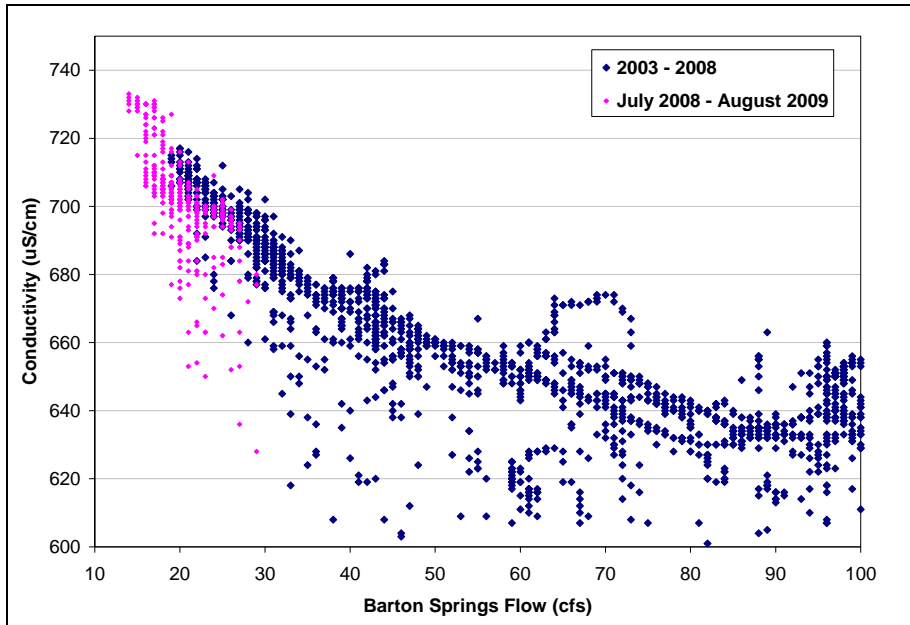


Figure 2. Daily average conductivity versus daily average discharge at main Barton Springs.

USGS datasonde continuous (15-minute logging intervals) was used to generate daily average conductivity. There were 2,182 daily average conductivity measurements from July 2003 to August 2009 assessed for temporal trends at main Barton Springs only. There was no attempt made to distinguish between different field instruments or deployments. In contrast to instantaneous conductivity over the period of record, the daily average conductivity from continuous monitoring yields an increasing trend from 2003 to 2009 at main Barton Springs (Table 13).

Prior to backward elimination, the full model for continuous conductivity was:

$$\text{Cont. Conductivity} = \text{flow_group} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Table 13. Continuous monitoring daily average conductivity ($\mu\text{S}/\text{cm}$) results.

Site	adj r2	Type	Estimate	Std Err	Pr>F
MBS	0.64	intercept	496.733	11.848	0.0000
		flow_group			
		recharge_group			
		bs_flow	-0.675	0.014	0.0000
		date	0.012	0.001	0.0000

Dissolved Oxygen

As with conductivity, instantaneous dissolved oxygen (DO) is measured by multiple field instruments (Table 14). A categorical variable was used to represent the different field instruments.

Table 14. DO data.

Collector	Site	Method	#	First	Last
USGS	BKDR	UNKNOWN	2	2005	2006
USGS	CS	UNKNOWN	2	2005	2006
USGS	ES	UNKNOWN	33	2003	2006
USGS	MBS	UNKNOWN	139	1969	2009
USGS	OM	UNKNOWN	28	2003	2005
USGS	UBS	UNKNOWN	27	2003	2005
WRE	BKDR	HORIBA WATER QUALITY METER	2	1996	1996
WRE	BKDR	HYDROLAB	1	2002	2002
WRE	BKDR	Quanta Probe	40	2002	2009
WRE	BS-D	HACH LDO PROBE	1	2006	2006
WRE	BS-D	HYDROLAB	1	1996	1996
WRE	BS-D	Quanta Probe	64	2004	2009
WRE	CS	HORIBA WATER QUALITY METER	5	1995	1996
WRE	CS	HYDROLAB	10	1991	2002
WRE	CS	Quanta Probe	22	2002	2009
WRE	ES	CALCULATION	125	2002	2009
WRE	ES	HORIBA WATER QUALITY METER	2	1996	1996
WRE	ES	HYDROLAB	4	2002	2006
WRE	ES	LAMOTTE TITRATION KIT	1	2007	2007
WRE	ES	Quanta Probe	63	2002	2009
WRE	MBS	CALCULATION	85	2002	2009
WRE	MBS	HORIBA WATER QUALITY METER	21	1995	2000
WRE	MBS	HYDROLAB	14	2001	2006
WRE	MBS	LAMOTTE TITRATION KIT	1	2005	2005
WRE	MBS	Quanta Probe	145	2000	2009
WRE	MBS	UNKNOWN	1	2006	2006
WRE	MBS	YSI Probe	1	2000	2000
WRE	OM	CALCULATION	122	2002	2009
WRE	OM	HORIBA WATER QUALITY METER	3	1995	1996
WRE	OM	HYDROLAB	3	2002	2006
WRE	OM	LAMOTTE TITRATION KIT	6	2005	2007
WRE	OM	Quanta Probe	31	2002	2009
WRE	UBS	CALCULATION	125	2002	2008
WRE	UBS	HYDROLAB	3	2002	2002
WRE	UBS	LAMOTTE TITRATION KIT	2	2007	2007
WRE	UBS	Quanta Probe	13	2002	2008

Prior to backward elimination, the full model for instantaneous DO was:

$$DO = method + method*date + recharge_group + bs_flow + date$$

Instantaneously measured DO is decreasing over time at main Barton Springs, Backdoor Springs, and Cold Springs but increasing over time at Upper Barton Springs. There is no temporal trend evident at Old Mill or Eliza Springs (Table 15).

Table 15. Instantaneous DO (mg/L) results.

Site	adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.06	intercept	11.943	2.282	0.0000
		method			
		method*date			
		recharge_group			
		bs_flow			
		date	-0.0003	0.0001	0.0699
CS	0.18	intercept	9.778	1.122	0.0000
		method			
		method*date			
		recharge_group			
		bs_flow			
		date	-0.0002	0.0001	0.0088
ES	0.65	intercept	3.739	0.177	0.0000
		method			
		method*date			
		recharge_group	0.331	0.116	0.0049
		bs_flow	0.029	0.002	0.0000
		date			
MBS	0.71	intercept	4.992	0.244	0.0000
		method			
		method*date			
		recharge_group	0.222	0.087	0.0113
		bs_flow	0.029	0.001	0.0000
		date	-0.0001	0.0000	0.0000
OM	0.25	intercept	4.381	0.211	0.0000
		method			
		method*date			
		recharge_group			
		bs_flow	0.020	0.003	0.0000
		date			
UBS	0.39	intercept	-1.419	2.080	0.4962
		method			
		method*date			
		recharge_group	0.440	0.150	0.0039
		bs_flow	0.039	0.004	0.0000
		date	0.0003	0.0001	0.0088

USGS continuous (15-minute logging interval) datasonde DO at main Barton Springs only was used to generate daily average DO measurements and also assessed for temporal trends. There were 1,907 measurements from July 2003 to August 2009. The model did not attempt to account for changes in instrumentation because there was insufficient metadata to differentiate between instrument deployments. Barton Springs continuous DO is also decreasing over time (Table 16).

Prior to backward elimination, the full model for continuous DO was:

$$\text{Continuous DO} = \text{recharge_group} + \text{bs_flow} + \text{date}$$

Table 16. Continuous daily average data on de DO (mg/L) results.

Site	adj r2	Type	Estimate	Std Err	Pr>F
MBS	0.83	intercept	12.5308	0.2709	0.0000
		recharge_group	0.2482	0.0257	0.0000
		bs_flow	0.0235	0.0004	0.0000
		date	-0.0005	0.0000	0.0000

Fecal coliform bacteria

Fecal coliform bacteria was assessed only at main Barton Springs, where sufficient number of samples exist (Table 17). Fecal coliform is no longer being measured by ATCHHSD in favor of *E. coli* monitoring. *E. coli* bacteria yield no statistically significant trends over time at any site. Temporal trends in fecal coliform were assessed at the spring outfall and at the downstream dam of Barton Springs Pool.

Table 17. Fecal coliform data.

Collector	Site	Method	#	First	Last
ATCHD	BS-D	SM 9222 D	487	2003	2009
ATCHD	MBS	SM 9222 D	1236	1995	2009
ATCHD	MBS	UNKNOWN	549	1991	1995

Prior to backward elimination, the full model for fecal coliform was:

$$Fecal = recharge_group + bs_flow + date$$

Fecal coliform may be increasing over time in Barton Springs, although there is no statistically significant temporal trend in the swimming pool (Table 18). The rate of increase is small based on the period of record, and the very low adjusted r^2 value indicates the high degree of variability in the measurements. Barton Springs continues to yield high water quality with indicator bacteria concentrations well below the State of Texas standard for safe contact recreation (Figure 3).

Table 18. Fecal coliform (col/dL) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BS-D	0.01	intercept	37.874	4.958	0.0000
		recharge_group	.	.	.
		bs_flow	-0.186	0.073	0.0113
		date	.	.	.
MBS	0.03	intercept	-19.142	6.830	0.0051
		recharge_group	-4.658	1.883	0.0135
		bs_flow	.	.	.
		date	0.003	0.000	0.0000

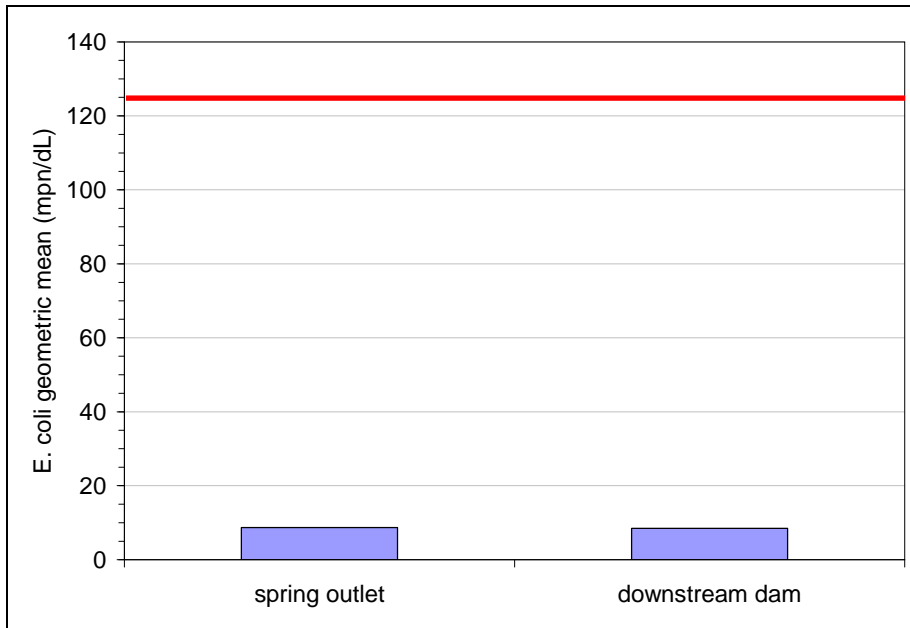


Figure 3. E. coli geometric means at Barton Springs and the downstream dam of Barton Springs pool versus the Texas 126 mpn/dL contact recreation standard in red.

Fluoride

Dissolved fluoride is measured by the USGS, while COA measures total fluoride (Table 19). A categorical variable was used to account for the varying filter fractions for main Barton Springs. However, because of the limited number of measurements at the other springs only total fluoride was assessed at these sites to parsimoniously reduce the number of variables in the model.

Table 19. Fluoride data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	4	2006	2006
Dissolved	USGS	MBS	79	1978	2009
Total	WRE	BKDR	50	1995	2009
Total	WRE	CS	55	1994	2009
Total	WRE	ES	63	1995	2009
Total	WRE	MBS	95	1991	2009
Total	WRE	OM	70	1994	2009
Total	WRE	UBS	44	1997	2008

Prior to backward elimination, the full model for fluoride was:

$$\text{Fluoride} = \text{filter} + \text{filter} * \text{date} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Fluoride may be decreasing from 1978 to 2009 based on regression models combining total and dissolved fluoride (Table 20). When analyzed separately, there is no significant trend in dissolved fluoride at main Barton Springs and total fluoride may be increasing from 1991 to 2009. Total fluoride yields increasing temporal trends at Eliza Springs, Old Mill Springs and Upper Barton Springs.

Table 20. Fluoride (mg/L) results.

Site	adj r2	Type	Estimate	Std Err	Pr>F
MBS (total and diss)	0.50	Intercept	3.5954	1.0480	0.0009
		Filter	-2.9686	0.9380	0.0020
		filter*date	0.0002	0.0001	0.0030
		recharge_group	.	.	.
		bs_flow	-0.0018	0.0002	0.0000
MBS (dissolved only)	0.33	Date	-0.0002	0.0001	0.0041
		Intercept	0.3278	0.0201	0.0000
		recharge_group	.	.	.
		bs_flow	-0.0014	0.0003	0.0000
BKDR	0.00	Date	.	.	.
		Intercept	0.1668	0.0234	0.0000
		recharge_group	.	.	.
		bs_flow	.	.	.
CS	0.06	Date	.	.	.
		Intercept	0.2865	0.0418	0.0000
		recharge_group	.	.	.
		bs_flow	-0.0012	0.0006	0.0578
ES	0.51	Date	.	.	.
		Intercept	0.0229	0.1175	0.8459
		recharge_group	.	.	.
		bs_flow	-0.0020	0.0003	0.0000
MBS	0.58	Date	0.00002	0.00001	0.0025
		Intercept	0.0689	0.0920	0.4568
		recharge_group	.	.	.
		bs_flow	-0.0021	0.0003	0.0000
OM	0.54	Date	0.00002	0.00001	0.0006
		Intercept	0.0505	0.1079	0.6419
		recharge_group	.	.	.
		bs_flow	-0.0022	0.0003	0.0000
UBS	0.17	Date	0.00002	0.00001	0.0009
		Intercept	-0.2193	0.1635	0.1919
		recharge_group	.	.	.
		bs_flow	.	.	.
UBS	0.17	Date	0.00003	0.00001	0.0191
		Intercept	-0.2193	0.1635	0.1919
		recharge_group	.	.	.
		bs_flow	.	.	.

Hardness as CaCO₃

Total hardness is measured by both the USGS and COA (Table 21). A categorical variable was used to represent the different collecting entities.

Table 21. Total hardness data.

Filter	Collector	Site	#	First	Last
Total	USGS	BKDR	4	2005	2007
Total	USGS	CS	3	2005	2007
Total	USGS	ES	51	2003	2006
Total	USGS	MBS	138	1978	2009
Total	USGS	OM	48	2003	2005
Total	USGS	UBS	48	2002	2005
Total	WRE	ES	11	1999	2009
Total	WRE	MBS	21	1999	2009
Total	WRE	OM	11	1999	2009

Prior to backward elimination, the full model for hardness was:

$$\text{Hardness} = \text{collector} + \text{collector} * \text{date} + \text{recharge_group} + \text{bs_flow} + \text{date}$$

Hardness data yields increasing temporal trends at Eliza, main Barton Springs, and Old Mill Springs over the period of record (Table 22). Fluoride was previously predicted to increase over time at main Barton Springs in the 2005 analysis.

Table 22. Hardness (mg/L as CaCO₃) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	1.00	intercept	400.0000	0.0000	.
		collector	.	.	.
		collector*date	.	.	.
		recharge_group	20.0000	0.0000	.
		bs_flow	0.0000	0.0000	.
		date	.	.	.
CS	0.00	intercept	308.0000	.	.
		collector	.	.	.
		collector*date	.	.	.
		recharge_group	-5.5000	.	.
		bs_flow	0.2500	.	.
		date	.	.	.
ES	0.12	intercept	206.0897	56.0365	0.0007
		collector	.	.	.
		collector*date	.	.	.
		recharge_group	.	.	.
		bs_flow	0.1789	0.0759	0.0238
		date	0.0059	0.0033	0.0833
MBS	0.24	intercept	272.6361	7.0003	0.0000
		collector	.	.	.
		collector*date	.	.	.
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0026	0.0005	0.0000

Table 22. (continued)

Site	Adj r2	Type	Estimate	Std Err	Pr>F
OM	0.09	intercept	113.2628	201.8059	0.5784
		collector	400.7762	210.6136	0.0658
		collector*date	-0.0249	0.0129	0.0624
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0269	0.0123	0.0367
UBS	0.24	intercept	285.0664	15.7045	0.0000
		collector	.	.	.
		collector*date	.	.	.
		recharge_group	.	.	.
		bs_flow	0.5187	0.1742	0.0065
		date	.	.	.

Magnesium

Dissolved and total magnesium have been measured by the USGS and COA (Table 23).

Generally consistent analytical methods (EPA 200.7) have been used. A categorical variable was used to account for differences in total and dissolved fractions. Differentiation of filter types also essentially accounts for differences in collecting entities.

Table 23. Magnesium data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	51	2003	2006
Dissolved	USGS	MBS	138	1978	2009
Dissolved	USGS	OM	48	2003	2005
Dissolved	USGS	UBS	48	2002	2005
Dissolved	WRE	BKDR	1	2000	2000
Dissolved	WRE	CS	2	1994	2000
Dissolved	WRE	ES	1	2000	2000
Dissolved	WRE	MBS	1	2000	2000
Dissolved	WRE	OM	3	1994	2000
Total	USGS	BKDR	2	2005	2006
Total	USGS	CS	2	2005	2006
Total	WRE	BKDR	52	1995	2009
Total	WRE	CS	55	1995	2009
Total	WRE	ES	66	1995	2009
Total	WRE	MBS	100	1991	2009
Total	WRE	OM	73	1995	2009
Total	WRE	UBS	44	1997	2008

Prior to backward elimination, the full model for magnesium was:

$$Mg = filter + filter*date + recharge_group + bs_flow + date$$

Magnesium yields increasing temporal trends at main Barton Springs, Eliza Springs and Cold Springs, but no statistically significant temporal trend at the other sites (Table 24). Magnesium previously yielded increasing trends over time at main Barton Springs (COA 2005).

Table 24. Magnesium (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.63	intercept	25.5028	0.7933	0.0000
		filter	-18.7297	2.3373	0.0000
		filter*date	0.0012	0.0001	0.0000
		recharge_group	1.8424	0.5063	0.0006
		bs_flow	.	.	.
		date	.	.	.
CS	0.51	intercept	14.2400	1.8984	0.0000
		filter	-1.0884	0.6061	0.0785
		filter*date	.	.	.
		recharge_group	.	.	.
		bs_flow	-0.0184	0.0057	0.0022
		date	0.0006	0.0001	0.0000
ES	0.64	intercept	14.7719	1.9213	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	1.2912	0.3801	0.0010
		bs_flow	-0.0350	0.0061	0.0000
		date	0.0005	0.0001	0.0000
MBS	0.59	intercept	22.4756	0.8318	0.0000
		filter	-5.7476	1.9507	0.0038
		filter*date	0.0004	0.0001	0.0046
		recharge_group	0.8288	0.3167	0.0098
		bs_flow	-0.0411	0.0051	0.0000
		date	0.0001	0.0001	0.0303
OM	0.17	intercept	22.1089	0.3978	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	2.2559	0.5196	0.0000
		bs_flow	.	.	.
		date	.	.	.
UBS	0.19	intercept	18.1544	1.9485	0.0000
		filter	-21.0074	6.2036	0.0014
		filter*date	0.0014	0.0004	0.0011
		recharge_group	.	.	.
		bs_flow	0.0436	0.0212	0.0453
		date	.	.	.

Nitrate+Nitrite as N

Dissolved nitrate plus nitrite as nitrogen (NO₃) is measured almost exclusively by the USGS, while total NO₃ is the standard parameter for COA and has also been measured by USGS (Table 25). A categorical variable was used to represent the different filter fractions.

Table 25. NO3 data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	43	2003	2006
Dissolved	USGS	MBS	116	1990	2009
Dissolved	USGS	OM	41	2003	2005
Dissolved	USGS	UBS	40	2003	2005
Dissolved	WRE	MBS	2	2006	2006
Dissolved	WRE	UBS	1	2007	2007
Total	USGS	MBS	57	1978	1992
Total	WRE	BKDR	62	1995	2009
Total	WRE	CS	57	1995	2009
Total	WRE	ES	67	1995	2009
Total	WRE	MBS	376	1986	2009
Total	WRE	OM	70	1995	2009
Total	WRE	UBS	45	1997	2008

Prior to backward elimination, the full model for NO3 was:

$$NO3 = filter + filter*date + recharge_group + bs_flow + date$$

NO3 yields increasing temporal trends at main Barton Springs and Backdoor Springs. NO3 values at Old Mill Springs yield decreasing temporal trends. No trends are observed at Eliza Springs, Cold Springs or Upper Barton Springs. NO3 was previously documented to be increasing in Barton Springs over time in the 2005 analysis (COA 2005).

Table 26. NO3 (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.15	intercept	-0.5615	0.7932	0.4818
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0002	0.0000	0.0014
CS	0.67	intercept	1.1051	0.1726	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	0.5926	0.1158	0.0000
		bs_flow	-0.0033	0.0017	0.0518
		date	.	.	.
ES	0.51	intercept	1.0769	0.0229	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	0.2859	0.0293	0.0000
		bs_flow	.	.	.
		date	.	.	.

Table 26. (continued)

Site	Adj r2	Type	Estimate	Std Err	Pr>F
MBS	0.38	intercept	1.0892	0.0669	0.0000
		filter	0.0624	0.0217	0.0042
		filter*date	.	.	.
		recharge_group	0.1930	0.0214	0.0000
		bs_flow	-0.0015	0.0003	0.0000
		date	0.00001	0.00000	0.0008
OM	0.33	intercept	2.0164	0.3631	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	0.3540	0.0760	0.0000
		bs_flow	0.0052	0.0012	0.0001
		date	-0.0001	0.0000	0.0001
UBS	0.00	intercept	2.1148	0.0480	0.0000
		filter	.	.	.
		filter*date	.	.	.
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.

Sample frequency for conventional analytes of 26 scheduled events per year is established by the City of Austin Texas Pollutant Discharge Elimination System (TPDES) MS4 permit. If reduced budget allowances for sampling mandate reduction or restructuring of sampling schedules, or if there is a desire to refocus sampling resources to new monitoring objectives like recent source water identification efforts, a sample frequency analysis may inform those decisions. Nitrate is a critical parameter for evaluating eutrophication of contributing zone creeks, and may be important in assessing aesthetic impacts to the pool from nuisance algal growth. Temporal trends in nitrate were not evident until the 2005 analysis, suggesting that using nitrate may be a conservative estimate of overall trend prediction sensitivity to sample frequency. An *a posteriori* sample frequency analysis was conducted on nitrate, systematically sub-sampling the WRE dataset and repeating the trend analysis. WRE sampling frequency may be reduced by up to 75% (only 7 events per year) with no loss of significant prediction of temporal trends over the period of record, although the relationship to Barton Springs flow becomes non-significant (Table 27). Sampling events may be reduced by 50% with no change in prediction estimates for either temporal trends or relationship to Barton Springs flow.

Table 27. Nitrate WRE sample frequency reduction affect on regression model predictions for main Barton Springs (least significant regression models shown for each alternate sample frequency).

Sample Freq	adj r2	Type	Estimate	Std Err	Pr>F
all samples	0.38	intercept	1.08921	0.06694	0.0000
		filter	0.06238	0.02166	0.0042
		filter*date			
		recharge	0.19301	0.02138	0.0000
		bs_flow	-0.00148	0.00033	0.0000
		date	0.00001	0.00000	0.0008
50% reduction in frequency	0.42	intercept	1.04623	0.07221	0.0000
		filter	0.05043	0.02275	0.0275
		filter*date			
		recharge	0.23376	0.02549	0.0000
		bs_flow	-0.00091	0.00040	0.0234
		date	0.00001	0.00000	0.0062
75% reduction in frequency	0.38	intercept	0.95607	0.07957	0.0000
		filter	0.04819	0.02810	0.0880
		filter*date			
		recharge	0.27046	0.02671	0.0000
		bs_flow			
		date	0.00001	0.00000	0.0205

Non-Carbonate Hardness

Filtered non-carbonate hardness is sampled almost exclusively, and only by the USGS (Table 28). Only dissolved non-carbonate hardness was included in the analysis.

Table 28. Non-carbonate hardness (mg/L) data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	4	2005	2007
Dissolved	USGS	ES	48	2003	2006
Dissolved	USGS	MBS	103	1990	2009
Dissolved	USGS	OM	42	2003	2005
Dissolved	USGS	UBS	44	2003	2005
Total	USGS	MBS	10	1978	1983

Prior to backward elimination, the full model for non-carbonate hardness was:

$$NCH = recharge_group + bs_flow + date$$

Non-carbonate hardness is increasing over time at main Barton Springs, and may be increasing over time in Eliza Springs (Pr>F = 0.09). Non-carbonate hardness was previously predicted to be increasing over time only in recharge conditions at main Barton Springs (COA 2005), and was not previously assessed at Eliza Springs.

Table 29. Non-carbonate hardness (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	1.00	intercept	3.200	0.000	.
		recharge_group	34.050	0.000	.
		bs_flow	0.225	0.000	.
		date	.	.	.
CS	1.00	intercept	84.600	0.000	.
		recharge_group	-36.100	0.000	.
		bs_flow	0.050	0.000	.
		date	.	.	.
ES	0.43	intercept	-132.304	114.918	0.2601
		recharge_group	-18.609	4.108	0.0001
		bs_flow	.	.	.
		date	0.012	0.007	0.0981
MBS	0.11	intercept	29.291	14.067	0.0417
		recharge_group	-8.053	4.184	0.0591
		bs_flow	-0.120	0.067	0.0794
		date	0.002	0.001	0.0089
OM	0.38	intercept	75.571	3.590	0.0000
		recharge_group	-21.571	5.562	0.0008
		bs_flow	.	.	.
		date	.	.	.
UBS	0.32	intercept	62.143	3.084	0.0000
		recharge_group	-16.543	4.778	0.0022
		bs_flow	.	.	.
		date	.	.	.

pH

Water pH is measured by multiple different field instruments (Table 30), by both the USGS and WRE. A categorical variable was used to represent the different field instruments, which also differentiated between the USGS and WRE collecting entities.

Table 30. pH data.

Collector	Site	Method	#	First	Last
ATCHD	MBS	Quanta Probe	1	2003	2003
USGS	BKDR	UNKNOWN	3	2005	2007
USGS	CS	UNKNOWN	3	2005	2007
USGS	ES	UNKNOWN	54	2003	2006
USGS	MBS	UNKNOWN	179	1969	2009
USGS	OM	UNKNOWN	49	2003	2005
USGS	UBS	UNKNOWN	48	2003	2005
WRE	BKDR	HACH	3	1990	1995
WRE	BKDR	HORIBA WATER QUALITY METER	20	1995	2001
WRE	BKDR	HYDROLAB	2	1994	2002
WRE	BKDR	Quanta Probe	40	2002	2009
WRE	CS	HACH	2	1991	1995
WRE	CS	HORIBA WATER QUALITY METER	20	1995	2001
WRE	CS	HYDROLAB	14	1991	2002

Table 30. (continued)

Collector	Site	Method	#	First	Last
WRE	CS	Quanta Probe	22	2002	2009
WRE	ES	HORIBA WATER QUALITY METER	21	1995	2001
WRE	ES	HYDROLAB	2	2002	2006
WRE	ES	Quanta Probe	64	2002	2009
WRE	ES	SATUROMETER	2	2005	2008
WRE	MBS	COLE PARMER FIELD STICK	1	2001	2001
WRE	MBS	COLE PARMER PHCON10	1	2001	2001
WRE	MBS	HACH	6	1994	1996
WRE	MBS	HORIBA WATER QUALITY METER	165	1995	2001
WRE	MBS	HYDROLAB	12	2001	2004
WRE	MBS	Quanta Probe	147	2000	2009
WRE	MBS	SATUROMETER	1	2008	2008
WRE	MBS	YSI Probe	1	2000	2000
WRE	OM	HACH	1	1994	1994
WRE	OM	HORIBA WATER QUALITY METER	29	1995	2001
WRE	OM	HYDROLAB	2	2002	2006
WRE	OM	Quanta Probe	31	2002	2009
WRE	OM	SATUROMETER	3	2005	2008
WRE	UBS	HORIBA WATER QUALITY METER	23	1997	2001
WRE	UBS	HYDROLAB	3	2002	2002
WRE	UBS	Quanta Probe	14	2002	2008
WRE	UBS	SATUROMETER	1	2008	2008

Prior to backward elimination, the full model for pH was:

$$pH = method + method*date + recharge_group + bs_flow + date$$

pH yields decreasing (acidifying) trends over time for all sites except main Barton Springs. Main Barton Springs yields no statistically significant trends over time, but was predicted to be decreasing only in recharge conditions in previous analyses. WRE pH data collected at main Barton Springs using only the Quanta Probe yields no statistically significant trends since 2005. Unadjusted pH measurements in 2008 and 2009 appear to be slightly higher than preceding years but within normal historic ranges.

Table 31. pH (standard units) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.23	intercept	10.8132	0.9187	0.0000
		method	-2.3088	0.5245	0.0001
		method*date	0.0001	0.0000	0.0001
		recharge_group			
		bs_flow			
		date	-0.0002	0.0001	0.0004
CS	0.08	intercept	8.8342	0.8931	0.0000
		method	-1.0203	0.4525	0.0290
		method*date	0.0001	0.0000	0.0390
		recharge_group			
		bs_flow			
		date	-0.0001	0.0001	0.0843

Table 31. (continued)

Site	Adj r2	Type	Estimate	Std Err	Pr>F
ES	0.26	intercept	9.1692	0.4095	0.0000
		method	-0.9438	0.2517	0.0003
		method*date	0.0001	0.0000	0.0003
		recharge_group			
		bs_flow	-0.0016	0.0004	0.0005
		date	-0.0001	0.0000	0.0000
MBS	0.07	intercept	7.1008	0.0152	0.0000
		method	-0.3033	0.0787	0.0001
		method*date	0.00002	0.00000	0.0006
		recharge_group			
		bs_flow			
		date			
OM	0.32	intercept	9.1198	0.6494	0.0000
		method	-1.2445	0.4349	0.0056
		method*date	0.0001	0.0000	0.0057
		recharge_group	-0.1035	0.0542	0.0602
		bs_flow	-0.0034	0.0010	0.0014
		date	-0.0001	0.0000	0.0130
UBS	0.55	intercept	10.6938	0.5297	0.0000
		method	-1.7049	0.3641	0.0000
		method*date	0.0001	0.0000	0.0000
		recharge_group	-0.0859	0.0385	0.0307
		bs_flow	-0.0041	0.0012	0.0015
		date	-0.0002	0.0000	0.0000

Silica

Dissolved silica is measured exclusively by the USGS (Table 32). Silica was previously estimated to be increasing over time at main Barton Springs.

Table 32. Silica data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	51	2003	2006
Dissolved	USGS	MBS	138	1978	2009
Dissolved	USGS	OM	48	2003	2005
Dissolved	USGS	UBS	48	2002	2005

Prior to backward elimination, the full model for dissolved silica was:

$$Si = recharge_group + bs_flow + date$$

Dissolved silica is increasing over time in main Barton Springs (Table 33), in both recharge and non-recharge conditions when assessed separately. Dissolved silica is also increasing over time at Old Mill and Upper Barton Springs, but there is no significant temporal trend observed at Backdoor, Cold Springs or Eliza Springs.

Table 33. Silica (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	1.00	intercept	11.8200	0.0000	.
		recharge_group	3.5550	0.0000	.
		bs_flow	0.0475	0.0000	.
		date	.	.	.
CS	1.00	intercept	6.7700	.	.
		recharge_group	3.6550	.	.
		bs_flow	0.0125	.	.
		date	.	.	.
ES	0.15	intercept	11.5654	0.1867	0.0000
		recharge_group	.	.	.
		bs_flow	0.0054	0.0022	0.0223
		date	.	.	.
MBS	0.21	intercept	9.7365	0.3618	0.0000
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0001	0.0000	0.0000
OM	0.22	intercept	-1.6076	5.0025	0.7508
		recharge_group	0.2987	0.1371	0.0399
		bs_flow	.	.	.
		date	0.0008	0.0003	0.0123
UBS	0.13	intercept	-2.4568	6.8189	0.7218
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0009	0.0004	0.0371

Sodium

Dissolved sodium is typically collected by the USGS, while total sodium is collected by WRE (Table 34). A categorical variable was added to account for differences in filter fraction, which essentially captured differences in collection entities as well. A categorical variable was also added to account for the non-linear response of sodium to Barton Springs discharge at discharge values less than 38 ft³/s.

Table 34. Sodium data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	51	2003	2006
Dissolved	USGS	MBS	138	1978	2009
Dissolved	USGS	OM	48	2003	2005
Dissolved	USGS	UBS	48	2002	2005
Dissolved	WRE	BKDR	1	2000	2000
Dissolved	WRE	CS	2	1994	2000
Dissolved	WRE	ES	1	2000	2000
Dissolved	WRE	MBS	1	2000	2000
Dissolved	WRE	OM	3	1994	2000
Total	WRE	BKDR	52	1995	2009

Table 34 (continued)

Filter	Collector	Site	#	First	Last
Total	WRE	CS	55	1995	2009
Total	WRE	ES	63	1995	2009
Total	WRE	MBS	94	1991	2009
Total	WRE	OM	70	1995	2009
Total	WRE	UBS	45	1997	2008

Prior to backward elimination, the full model for sodium was:

$$Na = \text{filter} + \text{filter} * \text{date} + \text{recharge_group} + \text{low_flow} + \text{bs_flow} + \text{date}$$

An increasing trend in dissolved sodium was previously observed at main Barton Springs (COA 2005) only during non-recharge conditions. Based on this analysis, sodium is increasing over time only at Cold Springs (Table 35). No significant trend over time was identified at any other site. At main Barton Springs, sodium concentrations appear to be primarily related to Barton Springs discharge.

Table 35. Sodium (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.55	intercept	17.3998	0.9840	0.0000
		filter	-25.1404	3.1508	0.0000
		filter*date	0.0015	0.0002	0.0000
		flow_group	.	.	.
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.
CS	0.52	intercept	-1.8688	3.0536	0.5434
		filter	.	.	.
		filter*date	.	.	.
		flow_group	2.2844	0.7355	0.0032
		recharge_group	-2.8257	0.7763	0.0007
		bs_flow	.	.	.
		date	0.0010	0.0002	0.0000
ES	0.05	intercept	25.7023	3.1721	0.0000
		filter	.	.	.
		filter*date	.	.	.
		flow_group	-8.6267	3.6628	0.0208
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.
MBS	0.73	intercept	28.3821	0.6850	0.0000
		filter	.	.	.
		filter*date	.	.	.
		flow_group	-9.4967	1.1224	0.0000
		recharge_group	.	.	.
		bs_flow	-0.0517	0.0160	0.0016
		date	.	.	.

Table 35 (continued)

Site	Adj r2	Type	Estimate	Std Err	Pr>F
OM	0.75	intercept	67.6063	3.4344	0.0000
		filter	-28.9521	12.9899	0.0287
		filter*date	0.0018	0.0008	0.0275
		flow_group	-29.4244	4.1389	0.0000
		recharge_group	.	.	.
		bs_flow	-0.1265	0.0580	0.0321
		date	.	.	.
UBS	0.27	intercept	4.6837	1.4923	0.0028
		filter	-10.8853	4.5592	0.0208
		filter*date	0.0008	0.0003	0.0105
		flow_group	.	.	.
		recharge_group	.	.	.
		bs_flow	0.0591	0.0163	0.0007
		date	.	.	.

Strontium

The majority of strontium sampling has been done in the dissolved fraction by the USGS, although some samples for total strontium have been collected by WRE (Table 36). A categorical variable was added to represent the differences in collection entity and filter fraction. An additional categorical variable was used to account for differences in the non-linear relationship between strontium and Barton Springs discharge at low flows.

Table 36. Strontium data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	48	2003	2005
Dissolved	USGS	MBS	106	1990	2009
Dissolved	USGS	OM	49	2003	2005
Dissolved	USGS	UBS	48	2002	2005
Total	WRE	BKDR	7	1995	2009
Total	WRE	CS	10	1995	2009
Total	WRE	ES	9	2008	2009
Total	WRE	MBS	12	1995	2009
Total	WRE	OM	10	1995	2009
Total	WRE	UBS	2	2007	2008

Prior to backward elimination, the full model for strontium was:

$$Sr = \text{filter} + \text{filter} * \text{date} + \text{recharge_group} + \text{low_flow} + \text{bs_flow} + \text{date}$$

Strontium is decreasing over time at Eliza Springs (Table 37), but does not yield significant temporal trends at any other site. Although there is no trend at main Barton Springs, strontium values in 2008 and 2009 increased sharply due to an inverse relationship with flow thru the on-going drought but were generally within historic ranges (Figure 4).

Table 37. Strontium ($\mu\text{g/L}$) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	1.00	intercept	36.8589	17.3091	0.0865
		filter	-960.2194	40.2992	0.0000
		filter*date	0.0571	0.0025	0.0000
		low_flow	-69.9858	10.9160	0.0014
		recharge_group	85.1074	8.0943	0.0001
		bs_flow	1.9105	0.3070	0.0016
		date	.	.	.
CS	0.92	intercept	257.8416	25.1291	0.0000
		filter	-476.5150	89.5497	0.0011
		filter*date	0.0310	0.0056	0.0009
		low_flow	-89.5713	25.6800	0.0102
		recharge_group	.	.	.
		bs_flow	1.3224	0.6225	0.0713
		date	.	.	.
ES	0.98	intercept	6536.6443	1984.4966	0.0027
		filter	56665.1595	10803.8069	0.0000
		filter*date	3.2587	0.6157	0.0000
		low_flow	-794.3480	174.1740	0.0001
		recharge_group	154.8107	53.5068	0.0073
		bs_flow	-5.6936	1.7658	0.0032
		date	-0.2726	0.1235	0.0357
MBS	0.94	intercept	3087.9043	61.8599	0.0000
		filter	.	.	.
		filter*date	.	.	.
		low_flow	-1311.0988	112.3221	0.0000
		recharge_group	.	.	.
		bs_flow	-10.9881	1.5362	0.0000
		date	.	.	.
OM	0.82	intercept	2043.6302	138.2001	0.0000
		filter	.	.	.
		filter*date	.	.	.
		low_flow	-534.8344	153.9209	0.0015
		recharge_group	174.8845	79.1284	0.0344
		bs_flow	-7.3578	2.1308	0.0016
		date	.	.	.
UBS	0.30	intercept	360.0000	17.3581	0.0000
		filter	.	.	.
		filter*date	.	.	.
		low_flow	.	.	.
		recharge_group	89.9231	25.4748	0.0016
		bs_flow	.	.	.
		date	.	.	.

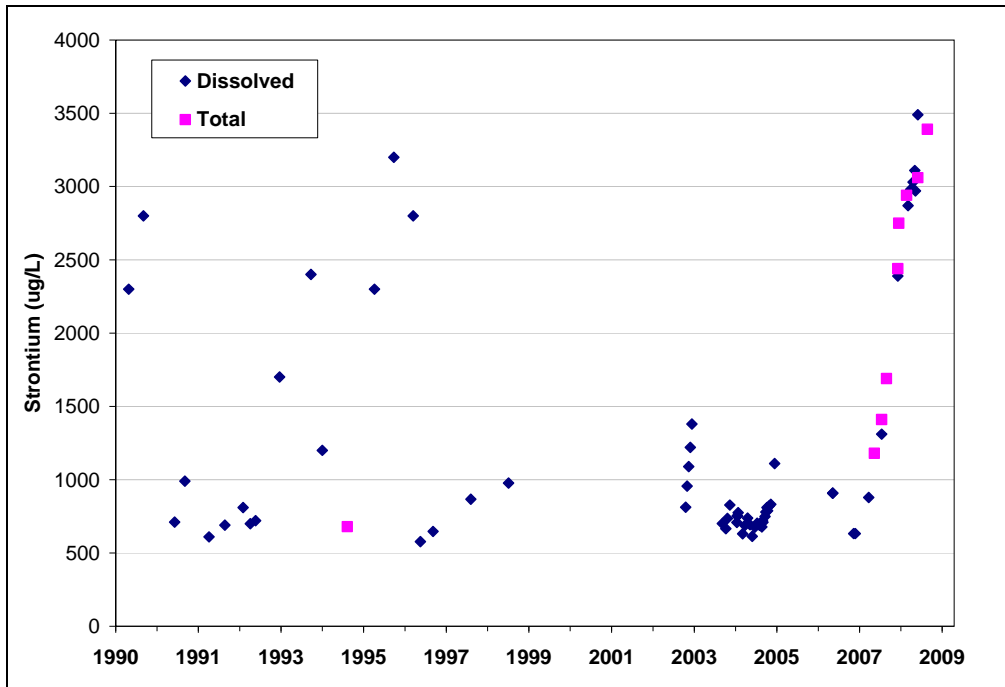


Figure 4. Dissolved and total strontium ($\mu\text{g/L}$) over time at main Barton Springs during non-storm influenced conditions.

Sulfate

Total and dissolved sulfate have been measured by the USGS, although WRE measures total sulfate (Table 38). Categorical variables were added to represent differences in filter fraction, collecting entity (and thus analytical method) and non-linear response to low flow.

Table 38. Sulfate data.

Filter	Collector	Site	#	First	Last
Dissolved	USGS	BKDR	4	2005	2007
Dissolved	USGS	CS	3	2005	2007
Dissolved	USGS	ES	20	2005	2006
Dissolved	USGS	MBS	35	2005	2009
Dissolved	USGS	OM	16	2005	2005
Dissolved	USGS	UBS	16	2005	2005
Total	USGS	ES	31	2003	2004
Total	USGS	MBS	105	1978	2004
Total	USGS	OM	32	2003	2004
Total	USGS	UBS	30	2003	2004
Total	WRE	BKDR	50	1995	2009
Total	WRE	CS	56	1994	2009
Total	WRE	ES	63	1995	2009
Total	WRE	MBS	93	1991	2009
Total	WRE	OM	70	1994	2009
Total	WRE	UBS	45	1997	2008

Prior to backward elimination, the full model for sulfate was:

$$SO_4 = \text{filter} + \text{filter} * \text{date} + \text{collector} + \text{collector} * \text{date} + \text{recharge_group} + \text{low_flow} + \text{bs_flow} + \text{date}$$

Sulfate yields increasing temporal trends at Backdoor Springs, Cold Springs (Pr>F = 0.06) and Eliza Springs. No temporal trends were observed at main Barton Springs, Old Mill or Upper Barton Springs. Sulfate was previously predicted (COA 2005) to be increasing at main Barton Springs only in recharge conditions, although no trend is now evident in either recharge or non-recharge conditions when analyzed separately.

Table 39. Sulfate (mg/L) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.22	intercept	-11.3726	8.5158	0.1883
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		collector*date	.	.	.
		low_flow	3.8010	1.8226	0.0426
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0018	0.0005	0.0014
CS	0.63	intercept	1001.9665	247.7370	0.0002
		filter	1003.7186	248.1876	0.0002
		filter*date	-0.0597	0.0147	0.0002
		collector	.	.	.
		collector*date	.	.	.
		low_flow	7.0655	2.9393	0.0203
		recharge_group	.	.	.
		bs_flow	0.1074	0.0453	0.0219
		date	0.0610	0.0146	0.0001
ES	0.42	intercept	24.7877	6.7663	0.0004
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		collector*date	0.0002	0.0001	0.0008
		low_flow	-7.5193	1.2377	0.0000
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0007	0.0004	0.0723
MBS	0.32	intercept	37.5113	1.0200	0.0000
		filter	.	.	.
		filter*date	.	.	.
		collector	3.0268	0.9350	0.0015
		collector*date	.	.	.
		low_flow	-7.9334	1.0615	0.0000
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.

Table 39. (continued)

Site	Adj r2	Type	Estimate	Std Err	Pr>F
OM	0.62	intercept	78.4022	4.8162	0.0000
		filter	-32.4049	16.1016	0.0476
		filter*date	0.0022	0.0010	0.0298
		collector	.	.	.
		collector*date	.	.	.
		low_flow	-34.8385	3.2004	0.0000
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.
UBS	0.12	intercept	15.6486	4.1039	0.0004
		filter	.	.	.
		filter*date	.	.	.
		collector	.	.	.
		collector*date	0.0002	0.0001	0.0610
		low_flow	.	.	.
		recharge_group	.	.	.
		bs_flow	0.1095	0.0446	0.0177
		date	.	.	.

Total Kjeldahl Nitrogen as N

Total TKN was collected by both the USGS and WRE (Table 40), although the USGS now measures dissolved (or filtered) TKN. Only total TKN was included in this analysis. TKN samples include a large proportion of values below detection limits, and trend analysis was confirmed with PHREG.

Table 40. TKN data.

Filter	Collector	Site	#	First	Last
Total	USGS	ES	8	2003	2005
Total	USGS	MBS	136	1978	2009
Total	USGS	OM	9	2003	2005
Total	USGS	UBS	8	2003	2005
Total	WRE	BKDR	31	1995	2004
Total	WRE	CS	35	1994	2004
Total	WRE	ES	37	1995	2008
Total	WRE	MBS	264	1986	2006
Total	WRE	OM	45	1994	2004
Total	WRE	UBS	34	1997	2004

Prior to backward elimination, the full model for TKN was:

$$TKN = collector + collector*date + recharge_group + bs_flow + date$$

TKN is decreasing over time at main Barton Springs (Table 41), with results from multiple linear regression confirmed by PHREG. There is no significant temporal trend observed at any other site by either regression method. Based on the lack of trend in ammonia, it may be inferred that organic nitrogen is decreasing over time at main Barton Springs. TKN was observed to be decreasing over time at main Barton Spring in the previous analysis (COA 2005).

Table 41. TKN (mg/L) results.

Site	Adj r ²	Type	Multiple Linear Regression			PHREG		
			Estimate	Std Err	Pr>F	Estimate	Std Err	Pr>x2
BKDR	0.00	intercept	0.1966	0.0272	0.0000			
		collector	.	.	.			
		collector*date	.	.	.			
		recharge_group	.	.	.			
		bs_flow	.	.	.			
		date	.	.	.			
CS	0.00	intercept	0.1512	0.0186	0.0000			
		collector	.	.	.			
		collector*date	.	.	.			
		recharge_group	.	.	.			
		bs_flow	.	.	.			
		date	.	.	.			
ES	0.04	intercept	0.0693	0.0380	0.0759			
		collector	.	.	.			
		collector*date	.	.	.			
		recharge_group	.	.	.			
		bs_flow	0.0008	0.0005	0.0991			
		date	.	.	.			
MBS	0.09	intercept	0.5319	0.0633	0.0000	.	.	.
		collector	-0.2371	0.1353	0.0809	0.6660	1.2578	0.5965
		collector*date	0.0000	0.0000	0.0607	0.0000	0.0001	0.9719
		recharge_group	.	.	.	-0.1953	0.2230	0.3813
		bs_flow	.	.	.	0.0018	0.0038	0.6259
		date	0.0000	0.0000	0.0000	-0.0004	0.0001	0.0001
OM	0.00	intercept	0.1515	0.0196	0.0000			
		collector	.	.	.			
		collector*date	.	.	.			
		recharge_group	.	.	.			
		bs_flow	.	.	.			
		date	.	.	.			
UBS	0.12	intercept	0.0825	0.0341	0.0232			
		collector	0.0868	0.0407	0.0429			
		collector*date	.	.	.			
		recharge_group	.	.	.			
		bs_flow	.	.	.			
		date	.	.	.			

Water Temperature

Instantaneous water temperature was measured by multiple different field instruments (Table 42). A categorical variable was used to account for the differences in field instrument.

Table 42. Temperature data.

Collector	Site	Method	#	First	Last
USGS	BKDR	UNKNOWN	3	2005	2007
USGS	CS	UNKNOWN	3	2005	2007
USGS	ES	UNKNOWN	44	2003	2006
USGS	MBS	UNKNOWN	160	1969	2009
USGS	OM	UNKNOWN	39	2003	2005
USGS	UBS	UNKNOWN	38	2003	2005
WRE	BKDR	HORIBA WATER QUALITY METER	20	1995	2001
WRE	BKDR	HYDROLAB	2	1994	2002
WRE	BKDR	Quanta Probe	40	2002	2009
WRE	BKDR	THERMOMETER (ALCOHOL)	3	1990	1995
WRE	CS	HORIBA WATER QUALITY METER	20	1995	2001
WRE	CS	HYDROLAB	10	1991	2002
WRE	CS	Quanta Probe	22	2002	2009
WRE	CS	THERMOMETER (ALCOHOL)	1	1995	1995
WRE	ES	HORIBA WATER QUALITY METER	21	1995	2001
WRE	ES	HYDROLAB	4	2002	2006
WRE	ES	Quanta Probe	64	2002	2009
WRE	ES	SATUROMETER	128	2002	2009
WRE	MBS	COLE PARMER FIELD STICK	1	2001	2001
WRE	MBS	COLE PARMER PHCON10	1	2001	2001
WRE	MBS	HORIBA WATER QUALITY METER	165	1995	2001
WRE	MBS	HYDROLAB	14	2001	2006
WRE	MBS	Quanta Probe	147	2000	2009
WRE	MBS	SATUROMETER	101	2002	2009
WRE	MBS	THERMOMETER (ALCOHOL)	4	1994	1995
WRE	MBS	UNKNOWN	1	2006	2006
WRE	MBS	YSI Probe	1	2000	2000
WRE	OM	HORIBA WATER QUALITY METER	29	1995	2001
WRE	OM	HYDROLAB	3	2002	2006
WRE	OM	Quanta Probe	31	2002	2009
WRE	OM	SATUROMETER	128	2002	2009
WRE	OM	THERMOMETER (ALCOHOL)	1	1994	1994
WRE	UBS	HORIBA WATER QUALITY METER	23	1997	2001
WRE	UBS	HYDROLAB	3	2002	2002
WRE	UBS	Quanta Probe	14	2002	2008
WRE	UBS	SATUROMETER	128	2002	2008

Prior to backward elimination, the full model for instantaneous temperature was:

$$Temp = method + method*date + recharge_group + bs_flow + date$$

Instantaneous temperature is increasing over time at main Barton Springs, Backdoor Springs and Upper Barton Springs (Table 43). Trends in temperature are most likely related to general trends in ambient air temperature in Austin. Although based on a limited number of measurements (n=68), instantaneous water temperature in the pool at the downstream dam is increasing over time as well (p=0.0278).

Table 43. Instantaneous temperature (°C) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
BKDR	0.16	intercept	17.8601	0.7657	0.0000
		method	1.3823	0.4371	0.0026
		method*date	-0.0001	0.0000	0.0029
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	0.0002	0.0000	0.0028
CS	0.00	intercept	20.1420	0.2350	0.0000
		method	.	.	.
		method*date	.	.	.
		recharge_group	.	.	.
		bs_flow	.	.	.
		date	.	.	.
ES	0.05	intercept	21.1513	0.1505	0.0000
		method	-0.8837	0.3800	0.0210
		method*date	0.0001	0.0000	0.0256
		recharge_group	0.2657	0.1225	0.0311
		bs_flow	.	.	.
		date	.	.	.
MBS	0.23	intercept	20.4371	0.2513	0.0000
		method	.	.	.
		method*date	0.0000	0.0000	0.0456
		recharge_group	0.4465	0.0717	0.0000
		bs_flow	-0.0039	0.0011	0.0004
		date	0.0000	0.0000	0.0032
OM	0.03	intercept	19.1184	0.6506	0.0000
		method	.	.	.
		method*date	.	.	.
		recharge_group	0.7739	0.3999	0.0545
		bs_flow	0.0178	0.0064	0.0060
		date	.	.	.
UBS	0.17	intercept	17.1438	1.6047	0.0000
		method	2.2321	0.5690	0.0001
		method*date	-0.0001	0.0000	0.0002
		recharge_group	0.2416	0.0864	0.0058
		bs_flow	0.0055	0.0024	0.0229
		date	0.0002	0.0001	0.0216

Daily average temperature trends were assessed at main Barton Springs using USGS datasonde data from 2003 to 2009, based on continuous monitoring (15-minute logging interval). There were 2,196 days with daily average temperature estimates in that time period. Daily average temperature is increasing over time at main Barton Springs from 2003 to 2009.

Prior to backward elimination, the full model for daily average temperature was:

$$Temp = recharge_group + bs_flow + date$$

Table 44. Daily average temperature (°C) results.

Site	Adj r2	Type	Estimate	Std Err	Pr>F
MBS	0.14	intercept	19.5860	0.2810	0.0000
		recharge_group	0.1383	0.0264	0.0000
		bs_flow	-0.0031	0.0004	0.0000
		date	0.0001	0.0000	0.0000

Conclusions

Barton Springs continues to maintain high water quality, although as exemplified by the decreases in DO and on-going increases in conductivity and nitrate, Barton Springs water quality is degrading over time. Trends in DO and nutrients are of particular concern due to the potential for impact on both the endangered salamander and aesthetic impairments in the swimming pool. Trend analyses for parameters yielding significant change over time are summarized (Table 45).

The majority (62%) of parameters with sufficient data yield no trend over time at any site (Table 2). There are few consistent temporal trend patterns between the springs assessed excepting the parameters with no temporal trends at any site. Calcium may be increasing at all sites, and pH may be decreasing at all sites except main Barton Springs.

The extreme recent drought may have had unexpected effects on some parameters like conductivity. The relationship of these parameters to Barton Springs discharge needs to be examined in more detail, and may be informative in the on-going source water identification efforts.

Temporal trends at main Barton Springs most frequently match temporal trends at Backdoor and Upper Barton Springs. Among the minor springs, Backdoor Springs appears to most closely match temporal trends at Cold Springs, while Eliza and Old Mill springs are most closely matched. There may be improvement in some parameters at main Barton Springs (chloride, fluoride, pH, potassium, sodium and sulfate).

WRE sampling frequency may be reduced by up to 75% (only 7 events per year) with no loss of significant prediction of temporal trends for nitrate over the period of record, although the relationship to Barton Springs flow becomes non-significant (Table 27). Sampling events may be reduced by 50% with no change in prediction estimates for either nitrate temporal trends or relationship to Barton Springs flow.

Table 45. Summary of trend analyses for parameters yielding significant trends over time.

Param	MBS 2005 Result	MBS	BKDR	CS	ES	OM	UBS
same as 2005 analysis							
ALKALINITY (AS CaCO ₃)	increasing ¹	increasing	no trend	no trend	no trend	no trend	no trend
CALCIUM	increasing	increasing	increasing ⁵	increasing ⁵	increasing ⁵	increasing ⁵	increasing ⁵
CONDUCTIVITY	increasing ¹	increasing	increasing	increasing	decreasing	decreasing	no trend
DISSOLVED OXYGEN	decreasing	decreasing	decreasing	decreasing	no trend	no trend	increasing
FECAL COLIFORM	increasing ¹	increasing	n/a	n/a	n/a	n/a	n/a
HARDNESS (AS CaCO ₃)	increasing	increasing	no trend	no trend	increasing	increasing	no trend
MAGNESIUM	increasing	increasing	increasing	increasing	increasing	no trend	no trend
NITRATE/NITRITE AS N	increasing	increasing	increasing	no trend	no trend	decreasing	no trend
NON-CARB. HARDNESS	increasing ¹	increasing	no trend	no trend	increasing	no trend	no trend
SILICA	increasing	increasing	no trend	no trend	no trend	increasing	increasing
STRONTIUM	no trend	no trend	no trend	no trend	decreasing	no trend	no trend
TKN AS N	decreasing	decreasing	no trend	no trend	no trend	no trend	no trend
WATER TEMPERATURE	increasing	increasing	increasing	no trend	no trend	no trend	increasing
changes from 2005 analysis							
BARIUM	no trend	increasing	no trend	no trend	no trend	no trend	no trend
CHLORIDE	increasing	decreasing	increasing	no trend	increasing	no trend	decreasing
FLUORIDE	no trend	decreasing	no trend	no trend	increasing	increasing	increasing
PH	decreasing ¹	no trend	decreasing	decreasing	decreasing	decreasing	decreasing
POTASSIUM	increasing ³	no trend	no trend	no trend	no trend	no trend	no trend
SODIUM	increasing ^{3,4}	no trend	no trend	increasing	no trend	no trend	no trend
SULFATE	increasing ¹	no trend	increasing	increasing	increasing	no trend	no trend

1. in recharge conditions only
2. increasing trend previously
3. dissolved fraction only
4. in non-recharge conditions only
5. total fraction only

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