Retrospective of Austin Public Health *E. coli* sampling at Barton Springs and Bull Creek District Park

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Abstract

Austin Public Health (APH), formerly known as the Austin/Travis County Health and Human Services Department (ATCHHSD), has routinely collected water samples for *E. coli* analysis from Barton Springs Pool since 2003 and the Bull Creek District Park since 2007. Although the public health concerns related to wastewater spills that initially prompted the sampling have long since subsided, the monitoring has continued for over twenty years. The resulting large data set (n = 7,071) has provided dependable insight into the spatial and temporal trends of these waterbodies. At the time of publication of this report, all sample locations are currently at or below the applicable standard thresholds and are either decreasing in concentration or have flat linear trend lines. Expected seasonal trends (higher concentrations in summer, lower in winter) are evident at all sites and exceedances of the threshold are few in contemporary samples. This prompted the question if sampling should continue in its current form, in a revised protocol, or be halted altogether. Based on a statistical analysis of the data and with consideration of promoting efficiency and effectiveness of resources, it is recommended that sampling should only be continued if 1) there is a specific hypothesis to test and/or an actionable use for the results, and 2) a new sampling plan is designed to provide statistically relevant results.

Keywords: *E. coli*, primary contact recreation, Barton Springs Pool, Bull Creek District Park

Introduction

E. coli is the contemporary surrogate for indication of fecal contamination of water bodies and is routinely assessed in water samples from the watersheds of Austin, Texas. *E. coli* is omnipresent in the fecal matter of warm-blooded animals and is therefore an appropriate indicator of a spectrum of enteric pathogens both species-specific and those with less host specificity. For example, fecal contamination from human sources would contain more pathogens of human concern than fecal contamination from pets (e.g., dogs, cats, etc.) or wildlife (e.g., raccoons, deer, birds, bats, etc.). Regardless, *E. coli* is the current standard parameter for risk of human health-related illness for which thresholds have widely been established.

E. coli as a standard for risk assessment

The risk of illness in humans can be increased by fecal contamination of water bodies during certain types of contact recreation. Title 30 Rule §307.3(a) of the Texas Administrative Code defines the following categories of contact recreation:

- **Primary contact recreation 1** – Activities that are presumed to involve a significant risk of ingestion of water (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing as defined by Texas Parks and Wildlife Code, §66.115, and the following whitewater activities: kayaking, canoeing, and rafting).
- **Primary contact recreation 2** – Water recreation activities, such as wading by children, swimming, water skiing, diving, tubing, surfing, handfishing as defined by Texas Parks and Wildlife Code, §66.115, and whitewater kayaking, canoeing, and rafting, that involve a significant risk of ingestion of water but that occur less frequently than for primary contact recreation 1 due to: (A) physical characteristics of the water body; or (B) limited public access.

Barton Springs Pool is primarily a large deep pool for which the use is promoted to be swimming and diving, which clearly meets the description for Primary Contact Recreation 1. The area downstream of the dam of Barton Springs Pool, commonly referred to "Barking Springs" (due to the prevalence of dog owners bringing their pets) is shallower and recreation is typically wading/sitting, with a much smaller occurrence of swimming, for which Primary Contact Recreation 2 would be a more appropriate categorization. Bull Creek District Park is mostly too shallow to swim, especially upstream; however, there are small areas with sufficient depth and patrons have been known to jump from rocks or swing from trees into a deep area near the downstream end of the park. Regardless of this occasional activity, the description of Primary Contact Recreation 2 befits the park.

In the 1940's the U.S. Public Health Service conducted studies to explore the relationship between bacterial water quality and waterborne illness. Stevenson (1953) reviewed these studies and recommended a median total coliform density not to exceed 2,300 counts per 100mL. In 1968 the National Technical Advisory Committee to the Federal Water Pollution Control Administration acknowledged this recommendation; however, they recommended using fecal coliforms instead of total coliforms and translated Stevenson's concentration to a threshold not exceed a log mean concentration of 200 fecal coliform colonies per 100mL. Although federal guidance and state standards imply an estimate of the risk related to contact recreational use, the history of these standards based on midcentury studies reveals a quantified link between illness and concentration to be even less clear because they are based on a further mathematical translation from fecal coliform to *E. coli* concentration (Porras 2020). Title 30 §307.7 establishes the current Texas Commission on Environmental Quality (TCEQ) standard for different categories of recreation.

- **Primary contact rec 1.** Geomean criterion 126 per 100mL; Single sample criterion 399 per 100mL
- **Primary contact rec 2**. Geomean criterion 206 per 100mL

Although an official assessment to determine if a waterbody meets State thresholds can only be conducted by the TCEQ, the guidelines on minimum data requirements and procedures for evaluating standards attainment are provided in the annual posting of the TCEQ Guidance for Assessing and Reporting Surface Water Quality in Texas. As of 2023, the current method of determining the geometric mean (geomean) for a data set is, in part, to use the most recent 20 samples over no more than a 7-year period. Additionally, although units for *E. coli* concentration in State thresholds are referenced as "colony forming units" (cfu) per 100mL this is functionally equivalent to the unit "most probable number" (MPN) per 100 mL used in the IDEXX Colilert method, and therefore, can be considered the same.

Baseflow Conditions

Most routine monitoring programs, such as the City of Austin Watershed Protection Department's (WPD) Environmental Integrity Index (EII), that provides data for use attainment for the TCEQ Clean Rivers Program and the Total Maximum Daily Load program, conduct sampling during baseflow conditions. Baseflow conditions are periods of time that exhibit "normal" flow in the creek that is not significantly influenced by residual stormflow. This is important because stormwater can transport a high concentration of suspended solids, dissolved pollutants, and microorganisms from the landscape in the Austin area (Glick 2005, Zhu and Glick 2017). For example, an analysis of 457 *E. coli* samples between 1999-2019 in Austin's Lady Bird Lake showed that *E. coli* concentrations were positively and highly correlated with rainfall amount the first day after rain, low correlation by the third day, and few correlations thereafter (Bellinger et al. 2020). The duration of residual effects from stormwater may be expected to vary considerably by many factors including watershed size/topography and the size/character of the storm; however, a standard operating procedure can be developed to define baseflow conditions that apply to typical storm events to avoid much of the effects. For example, since the mid 90's the WPD EII program has used the standard baseflow protocol with a sampling delay until:

- 24hrs after a rain event of 0.1" to 0.25",
- 48hrs after a rain event of 0.25" to 0.5", or
- 72hrs after a rain event > 0.5"

Unless samples are consistently collected under a baseflow criteria, assessment of a water body for recreational considerations can be complicated by outliers and conditions that may only exist right after a storm when total load would be naturally high.

Following an August 2007 sanitary sewage overflow occurring in the upper Bull Creek watershed, the Austin/Travis County Health and Human Services Department (now Austin Public Health or APH) associated complaints of gastrointestinal illness among people who swam at Bull Creek District Park to the overflow. Based on subsequent *E. coli* analysis from discrete samples, a routine monitoring regime of this reach of Bull Creek began later that year. Similarly, sampling at Barton Springs was initiated in 2003 following a nearby spill from a wastewater inceptor line (personal com. Scott Hiers 2023).

Barton Springs and Bull Creek District Park both attract an increasing number of people annually who engage in both primary and secondary contact recreation. Although sample results from the Bull Creek District Park have been the subject of several recent publications (COA 2008, Duncan et al. 2010, Wagner 2010, COA 2011, Johns 2017), the results from Barton Springs have apparently received less attention (Herrington and Johns 2011). This is likely because samples collected within Barton Springs rarely (0.08% of the time) exceeded the 20-sample geomean of >126 MPN/100mL, and infrequently (less than 1.8% of the time) exceeded 399 MPN/100mL, while Bull Creek sustained higher concentrations. With 20 years of data collected by APH at Barton Creek Pool and 16 years at Bull Creek District Park, a review of the data and future monitoring consideration is presented herein.

Methods

Water samples have been regularly collected for analysis of *E. coli* concentration at Barton Springs Pool at three locations (Barton Springs, BS-S, and BS-D) since April 2003 (Figure 1). An additional site downstream of the pool was added in July 2014 where there is focused recreational use at an area commonly known as "Barking Springs" (BS-BD).

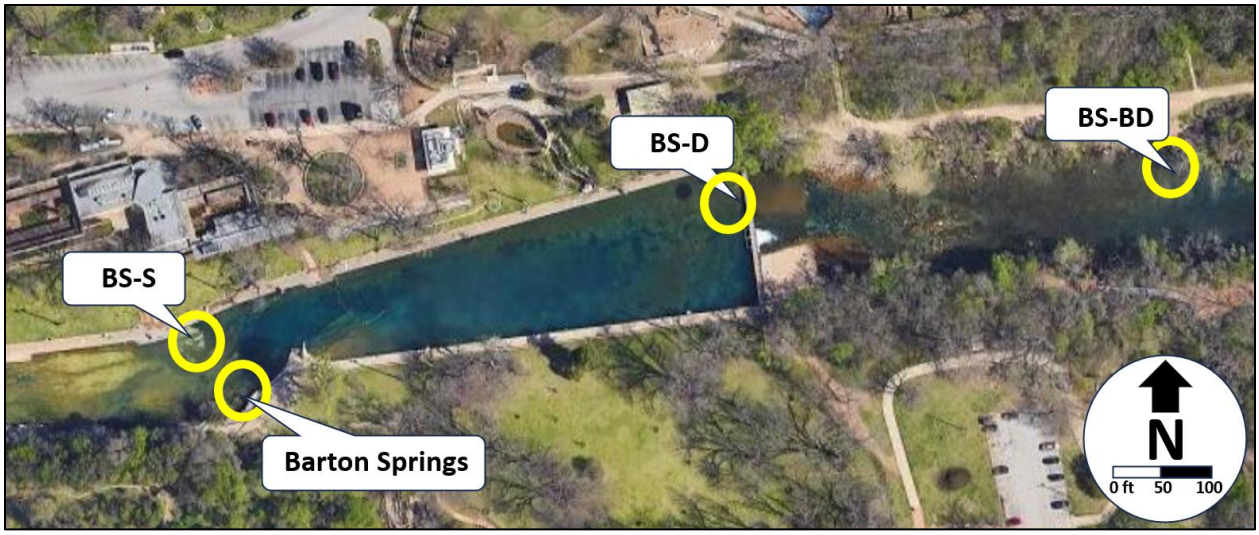

Figure 1. *E. coli* sample sites at Barton Springs Pool. Barton Springs is near the main springs just upstream of the diving board, BS-S is at the steps on the northside of the pool, and BS-D is just upstream of the dam. BS-BD is located downstream of the pool on the north bank.

Although water samples have been collected at various locations within the Bull Creek District Park over time, they have been regularly collected at two specific locations consistently for sixteen years. BCDP-1 is the most downstream site at the bottom of the park located at Lakewood Drive and BCDP-8 is the most upstream site located at the Loop 360 bridge (Figure 2). BCDP-1 is just downstream of a pool in the bend of the creek that is deep enough to swim, however BCDP-8 is only deep enough for wading. Both locations are popular for recreation, and therefore can be appropriately classified as primary contact recreation areas, however the stream reach between the two sites is primarily shallow, flat bedrock and unsuitable for swimming. Although the upstream portion of the park has changed little in the past few decades, the downstream portion of the park has received landscape restoration in recent years to improve the riparian health of the creek. The bank of the creek just south of the parking lot (adjacent to BCDP-1) has been transformed from an eroded, trampled and mowed bank to a protected Grow Zone that is now dense and diverse with vigorous vegetation where access is focused at key locations. A Grow Zone is a Watershed Protection Department strategy that couples cessation of mowing with signage to inform land managers and citizens of passive land management to restore riparian areas.

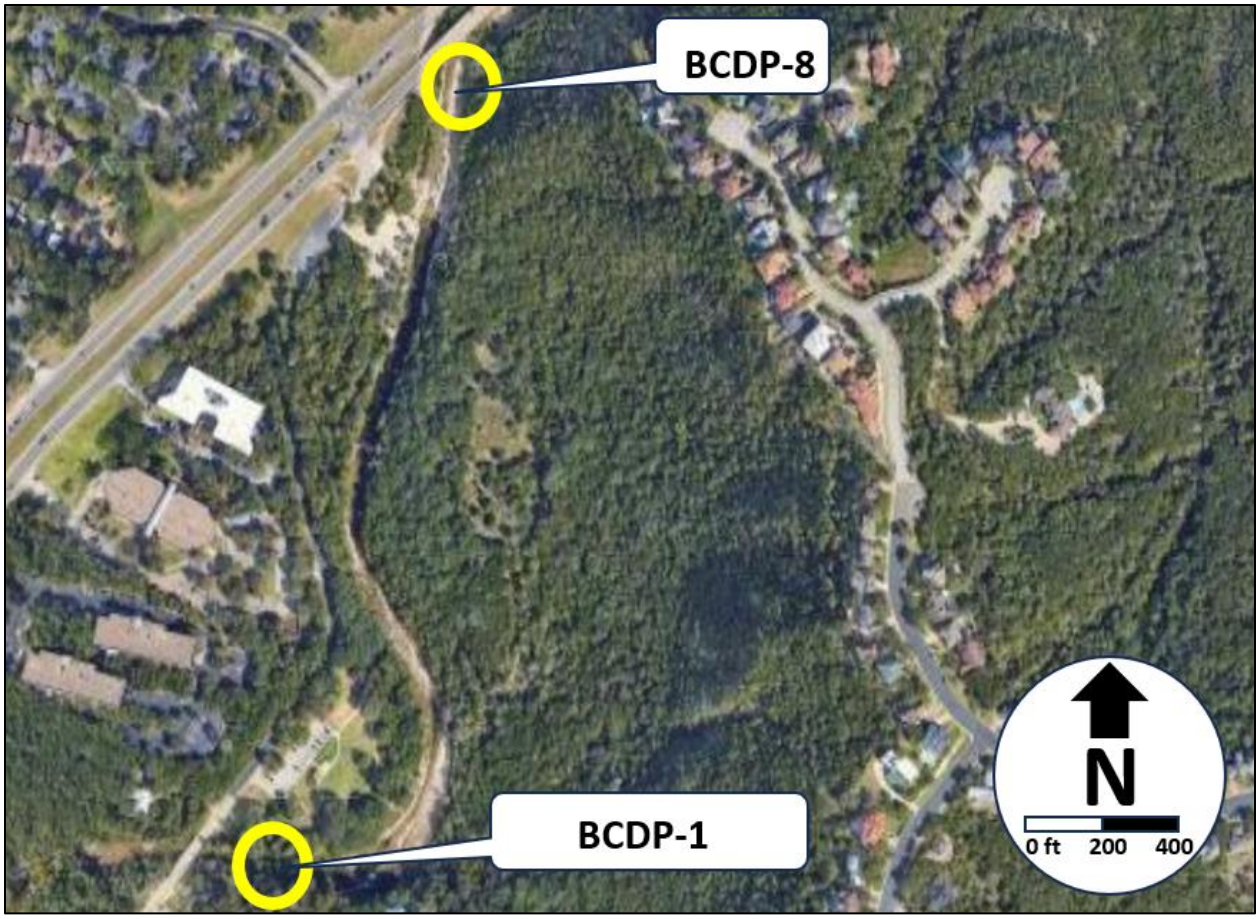

Figure 2. *E. coli* sample sites at Bull Creek District Park. BCDP-1 is located at the downstream end of the park ~90 feet upstream of Lakewood Dr and BCDP-8 is located at the upstream end of the park at the Loop 360 bridge.

The total number of samples processed since 2003 has produced an impressive 7,071 results for the combined Barton and Bull sites (Table 1).

Table 1. Total number of samples and date range used in this analysis. Samples collected within the pool include Barton Springs, BS-S, and BS-D, while samples collected in creeks include (BS-BD, BCDP1, BCDP8)

Site	Total number of samples	First Sample Date	Most recent sample used in this analysis
Barton Springs (near main springs)	1630	04/21/2003	08/02/2023
BS-S (north steps)	1634	04/21/2003	08/02/2023
BS-D (near dam)	1632	04/21/2003	08/02/2023
BS-BD (below dam)	849	07/31/2014	08/02/2023
BCDP-1(downstream)	663	03/10/2008	08/02/2023
BCDP-8 (upstream)	663	12/10/2007	08/02/2023

Samples are typically collected twice per week on either Mon/Wed or Tue/Th, however only a fraction of the samples have been collected on Friday, Saturday, or Sunday (Table 2). Standard APH protocol for sample collection include collection from the bank of the site using a collection rod to hold the 125ml bottle with sodium-thiosulfate. Samples are preserved on ice and delivered to the City of Austin, Austin Water laboratory.

Table 2. Number of samples by day of the week for the period of record. Weekly paired samples have primarily been collected during Mon/Wed, and less frequently on Tue/Thu, with very few samples collected on the weekend

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Total number of samples collected during the period of record	2,390	968	2,182	1,375	149	3	3

Data analysis for this report is primarily descriptive (average, median, percentiles, geometric mean, etc.) with some linear regression to distill an easily navigable summary of the large data set in the context of primary contact recreation thresholds as geomeans. Due to the nature of collecting samples early in the week and only in the morning, there is limited ability to explore high-resolution temporal trends such as variability through the day and/or days of the week to assess impacts from recreational use which are highest on the weekends. However, spatial trends (upstream/downstream at Bull Creek and within Barton Springs Pool) are possible. A Kruskal-Wallis 1-way ANOVA test was performed on data from Barton Springs Pool to determine if the three sample locations statistically differed. If significant differences were detected, a post-hoc Tukey test was used to determine dissimilarity between sites. This analysis lends insight to the number of sites that would be sufficient to characterize the condition of the pool.

Results

Although the average and median concentrations (Table 3) calculated from this large number of samples indicates generally low (11-328 MPN/100mL) concentrations compared to the full undiluted range of the IDDEX Colilert method (up to >2,419.6 MPN/100mL), these summary calculations are not necessarily indicative of a relative human health risk due to the skew of outlier values. For example, a single occurrence of a storm-related high value (such as 2,419.6 MPN/100mL) would need to be balanced with almost a hundred sample events of very low concentrations (<100MPN/100mL) to result in an average value under 126MPN. Conversely if the average or median values are very low (<100) then it may be interpreted that there are very few instances of high values, as is the case for all three sites within Barton Springs Pool. In this report, the average concentration is used to characterize sites but geomeans will be used instead of averages in the context of human health risk and primary contact recreation thresholds.

Table 3. Total number of samples used in this analysis with average and median values. Samples collected with the pool (Barton Springs, BS-S, BS-D) have similar concentrations, while samples collected in Barton Creek (below the pool) and Bull Creeks sites (BS-BD, BCDP1, BCDP8) are similar.

Site	Total number of samples	**Average** *E. coli* concentration (MPN/100mL)	**Median** *E. coli* concentration (MPN/100mL)
Barton Springs (near main springs)	1630	54	13
BS-S (north steps)	1634	60	11
BS-D (near dam)	1632	51	11
BS-BD (below dam)	849	255	99
BCDP-1(downstream)	663	228	70
BCDP-8 (upstream)	663	328	111

A large water quality monitoring data set, such as this one, spanning twenty years and thousands of samples would be expected to include several outliers, especially if the sample protocol did not prohibit collection of samples following storm events with inherently high variability. Box and whisker graphs (Figure 3) are an excellent format to summarize the spread of data but may be misleading when the outliers are visually emphasized due to the range of data and concentration of results. For example, the samples collected at BS-S span the full range of the IDEXX Colilert undiluted test and would visually

appear to have many high values; however, 98% of all samples (1585/1634) were below the 399 MPN/100 mL single grab threshold and most results are clustered at the bottom of the range.

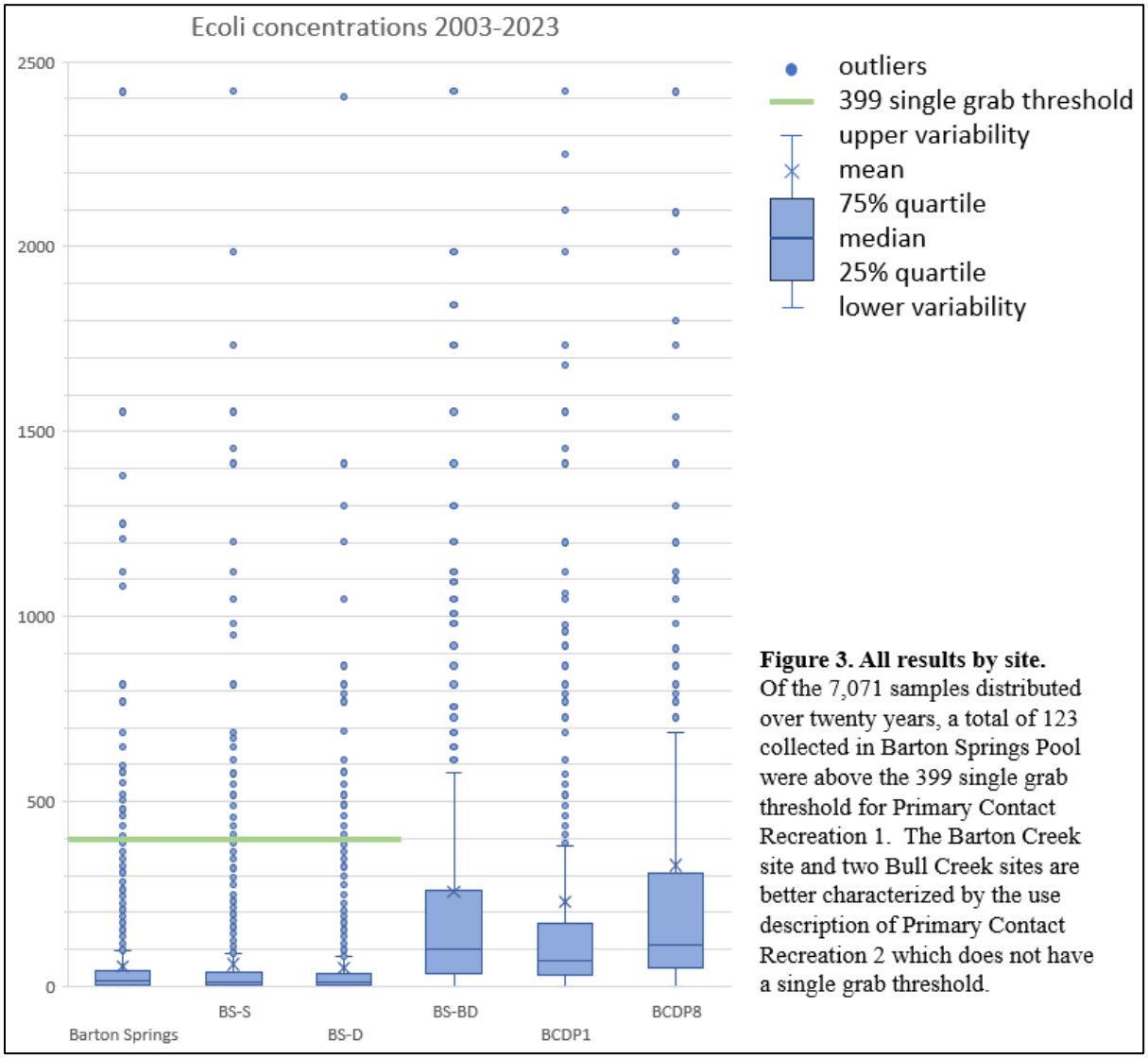

Figure 3. All results by site. Of the 7,071 samples distributed over twenty years, a total of 123 collected in Barton Springs Pool were above the 399 single grab threshold for Primary Contact Recreation 1. The Barton Creek site and two Bull Creek sites are better characterized by the use description of Primary Contact Recreation 2 which does not have a single grab threshold.

Although average concentration by site, by day of week (Figure 4) might appear to indicate some differences, the sample protocol to only collect morning samples primarily Monday-Thursday (98% of the time) renders interpretation unreliable. However, there are obvious and consistent differences in average concentrations from season to season with summer and spring concentrations higher than fall and winter (Figure 5). This may be expected for several reasons: warmer water temperatures allow bacteria in the water column to live longer, warmer weather promotes activity of warm-blooded mammals so more fecal matter can be expected on the landscape and in the water, and human recreation in the water is increased at popular swimming areas adding inputs and resuspends sediments. Seasonal differences were muted in the three pool sites, likely due to the dominance of spring discharge, and exaggerated in the creek sites (BS-BD, BCDP-1, BCDP-8).

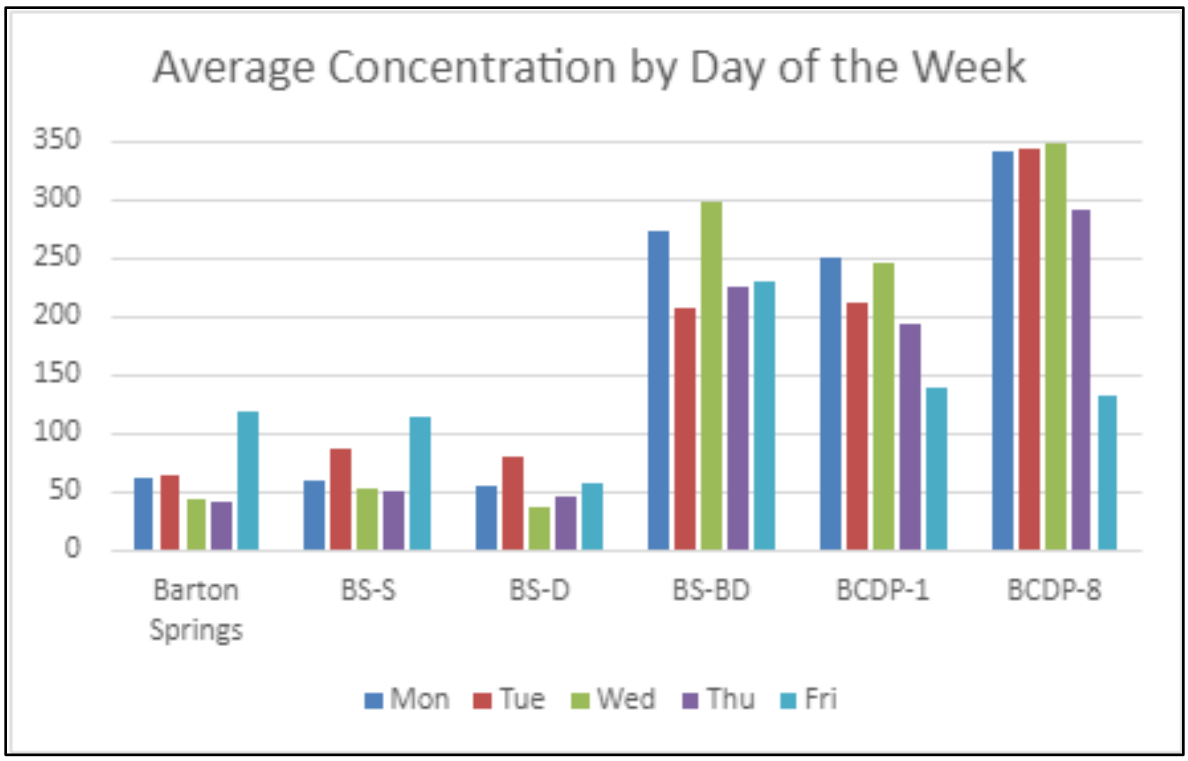

Figure 4. Average *E. coli* concentration for the entire period of record by site and weekday*. Although the somewhat higher concentrations on Fridays in Barton Springs Pool hints at a correlation with increased recreational use there were far fewer samples collected on Fridays (see Table 2) compared to other weekdays, so there is a lack of confidence in this association. Similarly, the lower concentrations on Fridays in Bull Creek are not dependable. No discernable differences between weekdays are apparent at the other sites Monday-Thursday. *weekends are not included due to lack of data.

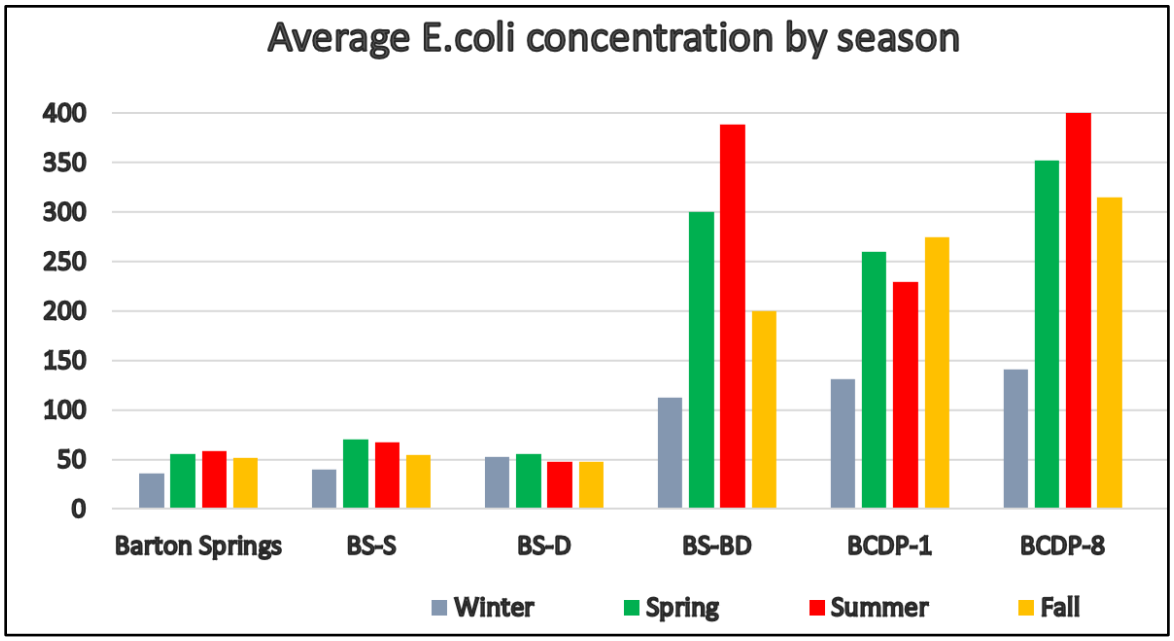

Figure 5. Average *E. coli* concentration for the entire period of record by site by season. Although concentrations throughout the year were similar at the three sites within Barton Springs Pool, the three sites in flowing channels indicate lower *E. coli* in winter and higher E. coli in summer.

The primary contact recreation threshold is applied to waterbodies that have a signficant risk of ingestion of water due to activities such as swimming or children wading, however the threshold is higher for sites where the activities occur less frequently due to the site characteristics or limitations in access. Both Primary Contact Recreation 1 and 2 have a geomean threshold (126 and 206 colonies/100mL, respectively); however, only Primary Contact Recreation 1 has a single grab threshold (399 colonies/100mL). Instances of exceednace of the thresholds for sites within the pool were few (2-3%)(Table 4). However, these overall summaries can be misleading regarding the current condition because many of the higher values occurred more than a decade ago.

Table 4. Sample exceedences of TCEQ thresholds

Sites that meet the use description of Primary Contact Recreation 1				
	Instances of a single grab sample >399 MPN		Instances of a rolling geomean* >126 MPN	
Site	instances/total n	overall percent	instances	percent
Barton Springs	38/1630	2.3%	0	0.0%
BS-S (steps)	50/1634	3.1%	4	0.2%
BS-D (dam)	35/1632	2.1%	0	0.0%

Sites that meet the use description of Primary Contact Recreation 2				
	No single grab sample threshold		Instances of a rolling geomean* >206 MPN	
Site			instances	percent
BS-BD (below dam)	n/a	n/a	146/849	17.2%
BCDP1 (Bull Creek District Park 1)	n/a	n/a	28/644	4.3%
BCDP8 (Bull Creek District Park 8)	n/a	n/a	163/663	24.6%

*The geometric mean is calculated from the 20 antecedent samples which typically spanned 3 months

A rolling geomean of the previous 20 samples for the entire period of record in Barton Creek Pool (Figure 5) at the three sites (Barton Springs, BS-S, BS-D) indicates a decades-long period below geomean thresholds with few exceptions (4 instances out of 4,896 events). The area of Barton Creek downstream of the pool known as Barking Springs (BS-BD) is a mix of creek water and pool discharge and is also hydrologically connected to Lady Bird Lake, typically exhibited higher *E. coli* concentrations than the pool with consistent, seasonal cycles (higher in summer, lower in winter) (Figure 6). Linear regression trendlines for all four sites in the Barton watershed were essentially flat , indicating a lack of directional change over time.

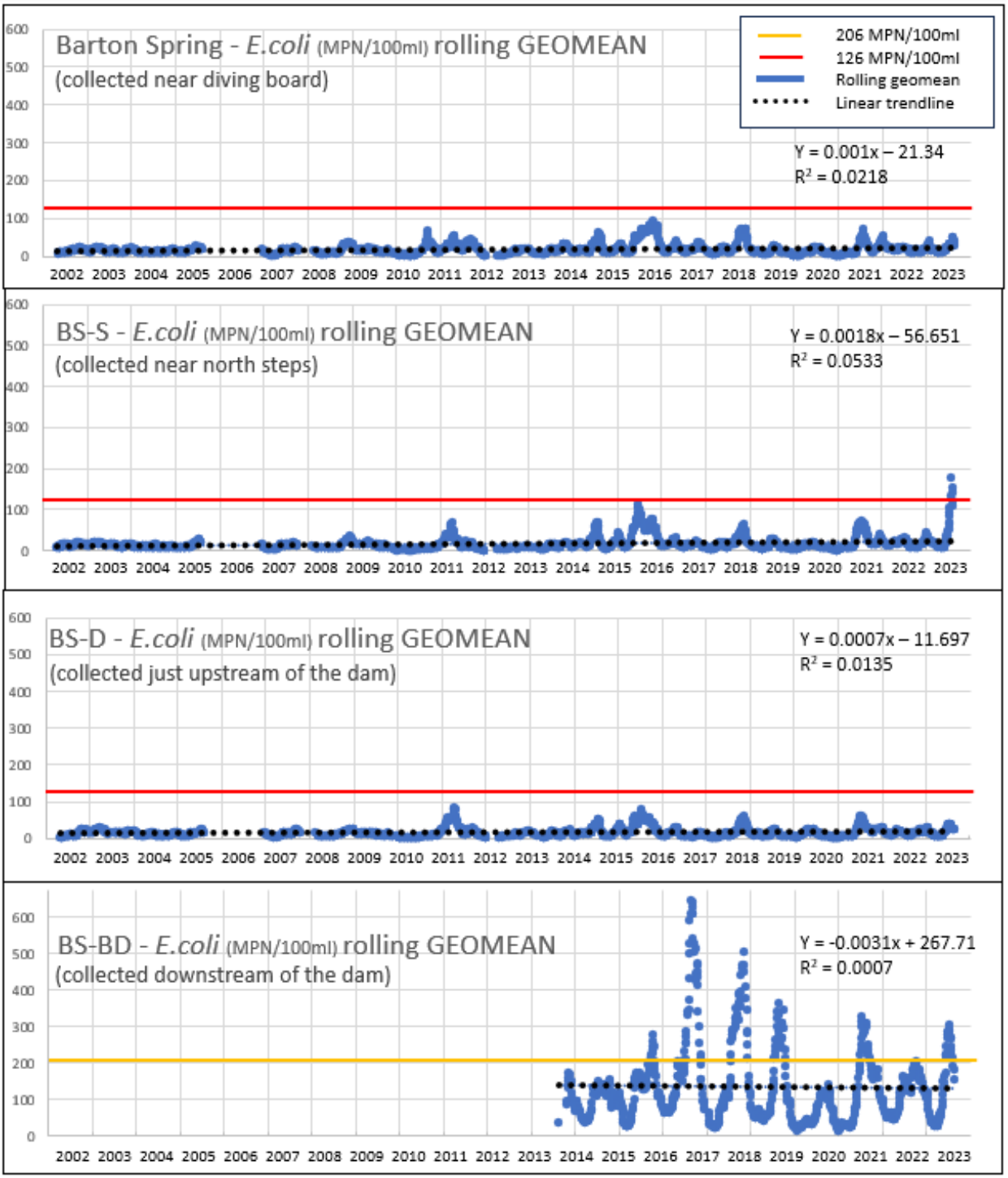

Figure 6. Barton Creek sites rolling 20-sample geomean (blue dots) and the TCEQ 126 colonies/100ml threshold (solid red line) for Primary Contact Recreation 1 for areas with the pool, and 206 colonies/100ml threshold (solid yellow line) for Primary Contact Recreation 2 for areas of the creek. The linear treandline for geomeans data is indicated by the black dotted line. The anomolous peak in summer 2023 at BS-S has return to low baseline levels as of publication time of this report.

Although geomeans for the three sites within the pool (Barton Springs, BS-S, BS-D) were lower than the Primary Contact Recreation 1 geomean threshold, results were typically higher at BS-BD which is a mix of pool and creek water. Linear trendlines for all Barton Springs sites were essentially flat (Figure 6). Site BS-S includes an *E. coli* concentration peak in August 2023; however, at the time of publication of this report a review of the subsequent samples indicated concentrations declined rapidly and remained low in the Fall.

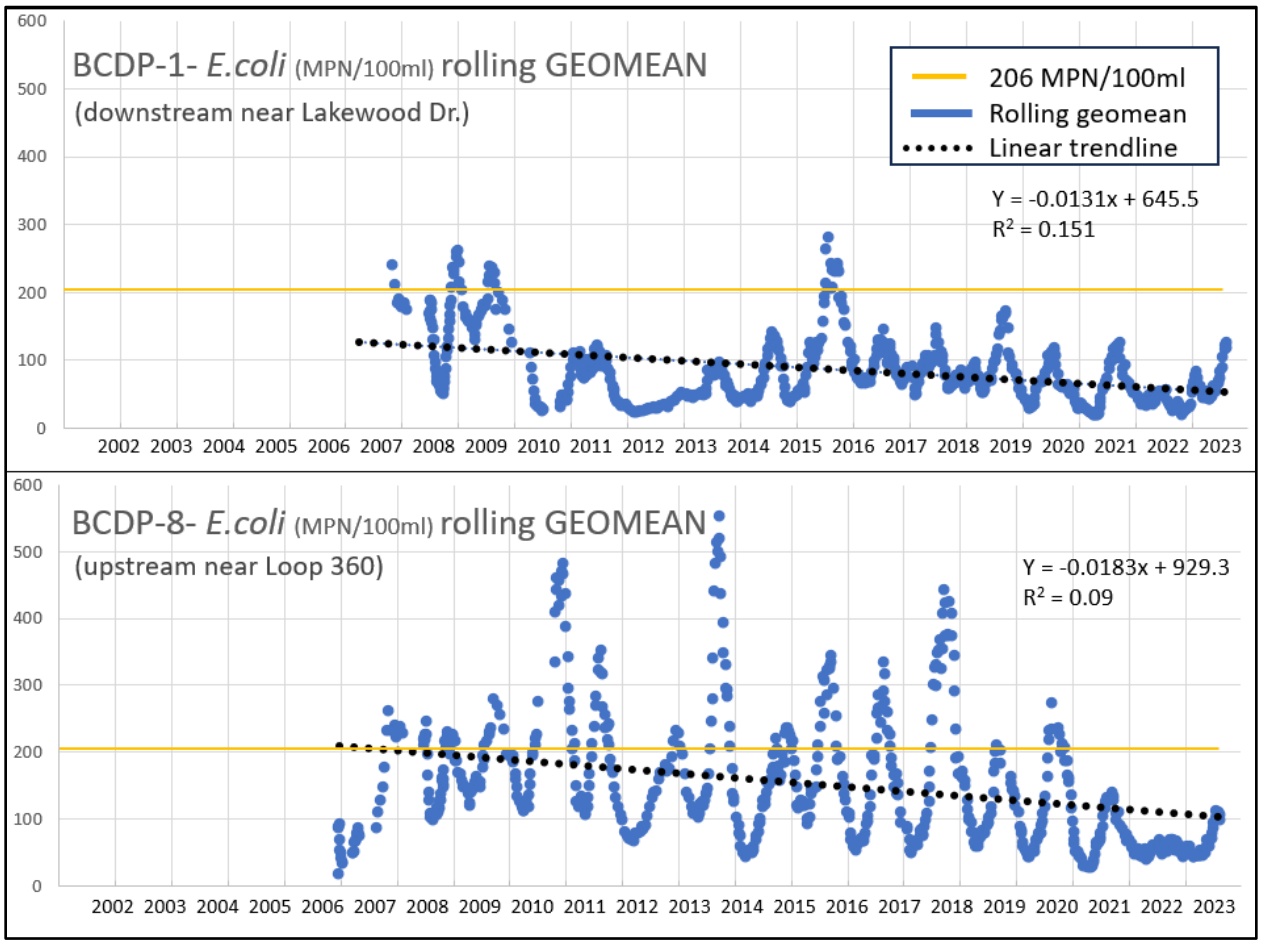

Figure 7. Bull Creek sites 20-sample rolling geomeans with linear treandline for all geomean data in the context of the TCEQ 206 colonies/100ml threshold for Primary Contact Recreation 2. Undulations in geomeans reflect seasonal variation in which higher values in the summer/low flow season (peaks) contrast with winter (troughs). Linear trendlines imply that overall concentrations are decreasing over time and are now compliant with contact recreation standards.

Rolling geomeans at the Bull Creek District Park upstream site (BCDP8) and downstream site (BCDP1) indicate similar concentrations and seasonal trends (Figure 7). The upstream site was typically higher than the downstream site, but both had the same seasonal patterns and trendline slope. Although both sites show some exceedances over the past 16 years, both indicate a trend decreasing geomean concentration over time, and both were under the Primary Contact Recreation 2 thresholds in recent years.

Sites within the pool were sampled on the same day within the same time period during each sample event. To determine if the data produced from these three discrete sites is either redundant or if they are

providing different information (i.e., a presence or a lack of statistically significant difference between sites) a Kruskal-Wallis 1-way ANOVA test was performed on the data. The Kruskal-Wallis test (n=1,619 sample events, $H = 14.73$, 2df, $P < 0.001$) identified a significant difference between sites, and further examination using a Post-hoc Tukey test indicated that:

Barton Springs	>	BS-D	($P < 0.001$)
Barton Springs	>	BS-S	($P = 0.01$)
BS-S	=	BS-D	($P = 0.775$)

These results indicate that there were no statistically significant differences between BS-D and BS-S, but *E. coli* concentrations were statistically higher at the Barton Springs site than the other two sites, and the large sample size provided high statistical power for observed differences. Although the Barton Springs site is higher than the other two pool sites, results should be viewed through the lens of health-risk relevance (e.g., concentration of *E. coli*). For example, the overall geomean of Barton Springs was 14.78 while the geomeans of the other two sites were 12.21 (BS-D) and 12.81 (BS-S), all three concentrations are well below any threshold of concern and the difference is small

Discussion

Analysis Limitation

Although most samples were collected during baseflow conditions, protocols were not established to prohibit sampling during times when residual stormflow was present. This problem likely contributed to the few abnormally high sample results in Bull Creek (as would be expected in stormflow-affected samples), elevating averages/geomeans and the number of instances that individual grab samples exceeded the contact recreation standard. However, this sampling effect is not noticeable in the results from sites within Barton Springs Pool because creek water flows through the bypass and does not mix with the spring-fed pool in all but the largest storms. If samples are collected in the future, a protocol should be established to limit samples to baseflow condition, and/or record the presence of stormflow in a manner that data can be filtered for analysis.

Although standardizing the time and weekday is beneficial to identifying some trends, it hampers how results can be interpreted. This data should not be used to determine what effect the intensity of recreation has on the concentration of suspended *E. coli* because 98% of the samples (155 of 7,070) were collected in the morning hours of Monday–Thursday. Records of daily attendance should not be paired with the data as it may not reflect relative proportional use in the morning hours especially in the fall/spring when mornings are cold, but afternoons are warm. In addition to an imbalance of data over the course of a day, weekday attendance can be assumed to be less than weekend attendance which presents a gap in the recreational use spectrum. Further complicating this, attendance at the gate may not reflect the total use and type of use within the pool. Vigorous use, as one might see during peak use in the summer can resuspend sediments which could elevate *E. coli* concentration in the water column because *E. coli* is known to attach to sediment particles (Wu 2019). Additionally, the presence of large numbers of people could contribute to the *E. coli* concentration through direct inputs. If these facets of recreational use related to human health risk were of interest, then future sample protocol would need to distribute time of collection either randomly or stratified over the course of a day and week. Ultimately, the concentrations within the pool have been consistently below the geomean threshold for decades, so a deeper dive does not appear to be warranted. Similarly, pursuing additional resolution at Bull Creek Dog Park would likely be purely academic as the health risk appears to be below applicable geomean threshold, especially in the downstream area where swimming is possible.

Fortunately, the extremely large data set provides confidence in spatial and temporal trends and comparisons between sites. The following sections explore data in three areas: Barton Springs Pool, the area downstream of the pool, and the Bull Creek District Park.

Barton Springs Pool

Barton Springs Pool meets the description of Primary Contact Recreation 1 for which there is both an established geomean threshold (of 126 colonies per 100mL) and a single grab threshold (399 colonies per 100ML). The springs deliver a large volume of high-quality water from the Edwards Aquifer and the culvert (bypass) located under the deck on the west side of the pool directs creek flow around the pool virtually ensuring the water is consistently low in *E. coli* barring some leak/overflow in wastewater infrastructure. The typical lack of creek flow mixing with the pool mutes most effects of storm-influence on samples. Accordingly, the average and median *E. coli* concentrations for the three pool sites were very low (between 11–60 MPN/100ml), and the 20-sample rolling geomeans over time were reliably under the 126 MPN/100ml threshold for contact recreation. Although some grab samples exceeded the 399 MPN/100ml threshold, they represented less than 3% of the total (123 out of 4896) and were likely the result of anomalies such as large storm events, very low flow conditions, or samples that captured suspended sediments from patrons entering/exiting/or stirring up the water. A previous investigation of elevated concentrations near the spring head (site "Barton Springs") indicated this phenomenon may be due to the apparently suitable habitat for wildlife (e.g., racoons) seeking shelter in the fault near the spring, birds or other animals resting or feeding on the algal mats (Herrington and Johns 2011).

Although there is variability between the three sites, the rolling geomeans were virtually indistinguishable so it can be inferred that any one of the three sites would be sufficient to characterize the conditions in the pool. An analysis of variability between the three sites revealed that there was a statistically significant difference in which the Barton Springs site is slightly higher than the other two sites (BS-S and BS-D). Therefore, if continued sampling is desired, cost savings could be realized by limiting sampling to a single site within the pool, and the logical site to be sampled would be Barton Springs since it is slightly higher and would be a more conservative assessment of risk.

Temporal trend lines were effectively flat over 20 years, and therefore no future increase or decrease of *E. coli* within the pool is anticipated. A recent peak at site BS-S (north steps) this summer of 2023 was apparent; however, at the time of publication of this report, a review of concentrations during the Fall indicated subsidence back to low or very-low concentrations. Seasonal fluctuations are consistent such that summer months have higher concentrations than winter months. This could be for several reasons, such as typically lower spring flow in the summer reducing dilution and increasing residence time in the pool. It could also result from increased recreation resuspending sediment and source inputs which may also be exacerbated by increased activity of other warm-blooded animal inputs (e.g., birds, racoons) in the pool. Since the pool maintains a relatively consistent temperature year-round, it is unlikely that the seasonal fluctuation in the pool is related to temperature.

Downstream of Barton Springs Pool

The expected recreational use downstream of Barton Springs (site BS-BD) is categorically different than that within Barton Springs Pool. In the pool a diving board, deep water, and world-renowned swimming conditions all lead to a significant risk of ingestion of water. In contrast, the area below the pool is not as deep, does not have a diving board and is not advertised or condoned as an area for swimming. It is, however, intensely used for recreational wading, and is a popular site for people experiencing homelessness, and is frequently used by dog owners to allow their pets to swim because pets are not allowed within the pool. The water in this area is the same elevation as Lady Bird Lake and becomes increasingly similar chemically downstream toward the confluence with the lake.

Average concentrations downstream of the pool were roughly 4-5 times higher than sites within the pool and median concentrations were 7-9 times higher, but the average (255 MPN/100ml) and the median (99 MPN/100ml) concentrations were still relatively low for an urban water resource. The 20-sample rolling geomeans over time were significantly higher and more variable than the pool and were similar in concentration and seasonal variation to Bull Creek sites. The linear best fit line for rolling geomean was well under the 206 colonies per 100mL threshold for Primary Contact Recreation 2, and temporal trend lines were flat indicating that although exceedances of the geomean are known to occur (primarily in the summer), the site is largely in compliance and generally unchanging over time.

Bull Creek District Park

The expected recreational use at Bull Creek District Park is more like that of Barking Springs, downstream of Barton Springs Pool. The upstream site (BCDP-8) is so shallow that swimming is not possible, but the frequent wading by patrons (adults and children) demonstrates appropriateness of Primary Contact Recreation 2 category. While the downstream site (BCDP-1) does have a small area that is deep enough for swimming, use is infrequent and so Primary Contact Recreation 2 is more appropriate. Fortunately, *E. coli* concentrations were lower at this downstream site than at the upstream site.

Rolling geomeans revealed significant seasonal changes (high summer, low winter). The upstream site (BCDP-8) was typically higher than the downstream site (BCDP-1) which may indicate that the source(s) of *E. coli* contamination are potentially at, or above, the first crossing of Capital of Texas Highway (Loop 360). There are several potential factors as to why this site might have higher concentrations. For example, the Loop 360 bridge is habitat for barn swallows that tend to build their nests over waterways which could locally increase *E. coli* during nesting season (March-September). This is consistent with higher summer concentrations and speculations by Merin (2017) that avian inputs may contribute significantly to the total loading. Increases in concentration during the summer could also be caused by general increases in warm-blooded animal activity and inputs from wildlife (e.g., deer, raccoon, coyotes, etc.). Animal activity generally declines in the winter due to colder temperatures and reduced food availability. The reach of creek between the upstream site (BCDP-8) and downstream site (BCDP-1) is very shallow (typically less than 0.3 m), limestone bedrock substrate, and has an open canopy which may attenuate *E. coli* concentrations due to UV sterilization during sunny days. These hypotheses could be tested with a modified sampling regime.

Although both the upstream and downstream sites had similar geomeans before 2010, which were above the Primary Contact Recreation 2 threshold, both sites have trended lower in concentration and are now largely below the threshold.

Conclusions

Twenty years of sampling conducted by APH has provided dependable insight to the character and trends of *E. coli* concentrations in Barton Springs and Bull Creek District Park. Continued sampling in its current form is unlikely to reveal additional information and so should either be modified to answer specific questions or stopped. It can be inferred from the data that:

- Barton Springs Pool sites meet the geomean threshold established for Primary Contact Recreation 1
- Creek sites (BS-BD, BCDP-1, and BCDP-8) meet the threshold for Primary Contact Recreation 2
- Concentration trends are flat at Barton sites and trend lower in concentration at Bull Creek sites.

Outliers that exceed the single grab sample threshold can be expected to occur in such a large data set, especially collected under protocols that do not prohibit storm-influence such as the current program.

Recommendations

To promote efficiency and effectiveness, the current sampling plan should be suspended because the 20 years of data have yielded confidence in patterns and trend lines and all sites appear to be currently under the appropriate thresholds. If future sampling is desired, it should only be conducted if 1) there is a specific hypothesis to test, and/or an actionable use for the results; and, 2) a new sampling plan is designed scientifically to provide statistically relevant results. If continued sampling is determined to be necessary, the frequency and number of sites could be greatly reduced and will yield similar results. For example, Barton Springs Pool could only be sampled at one location (Barton Springs) and still yield similar concentrations and trends adequately characterizing the condition of the pool, and Bull Creek District Park could only be sampled at the upstream location (BCDP-8) also yielding similar concentrations and trends with confidence that the downstream site is likely lower. Frequency of sampling could be reduced to that which is necessary (i.e., weekly, monthly, seasonally, etc.) to meet the needs of the designated hypothesis or use. Regardless, if any samples are collected in the future, a protocol should be established to either limit samples to baseflow conditions or record the days since rain, and amount of antecedent rain in the watershed such that data can be filtered appropriately for analysis.

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