

Figure 9. E. coli (mpn/dL) versus mean daily stream flow (ft³/s) for the Lakewood and Loop 360 sites using all data.

Correlation between E. coli and antecedent rainfall was assessed by Kendall's tau-b correlation test using the number of days since measurable rainfall and rainfall total in the 72 hours prior to sampling as measured by the National Weather Service gauge at Camp Mabry (Table 6). In general, E. coli levels were inversely related to number of days since rainfall and positively related to rainfall totals within the past 72 hours at the Lakewood and Loop 360 monitoring locations. There was no correlation with rainfall during the closure period, although the rainfall totals and number of rainfall days from December to May 2010 were consistent with averages from the same groups of months averaged since 2000 suggesting that there was nothing unusual about the climatic patterns during the closure period.

Table 6. Results of Kendall's tau-B correlation of *E. coli* with number of days since rainfall and total rainfall in the 72 hours prior to sampling. Green shaded cells show significant correlation ($\alpha < 0.05$).

Period	Site	N	Days Since Rain		Rain in Last 72h	
			Tau-b	Pr>= Tau	Tau-b	Pr>= Tau
Historic	Loop 360	17	-0.36	0.05	0.42	0.03
PostSpill	Lakewood	158	-0.19	0.01	0.26	0.01
PostSpill	Loop 360	20	-0.12	0.46	0.21	0.25
PostEducation	Lakewood	110	-0.15	0.03	0.15	0.04
PostEducation	Loop 360	96	-0.15	0.04	0.17	0.03
PostEducation	Spicewood	10	0.11	0.65	-0.18	0.50
PostEducation	Trib 2	4
PreClosure	Lakewood	33	-0.05	0.72	0.26	0.05
PreClosure	Loop 360	27	-0.29	0.04	0.43	0.01
PreClosure	Spicewood	7	-0.1	0.75	0.07	0.85
PreClosure	Trib 2	2
Closure	Lakewood	33	0.05	0.71	0.14	0.27
Closure	Loop 360	35	-0.13	0.29	0.16	0.19
Closure	Spicewood	12	0.05	0.83	-0.17	0.48
Closure	Trib 2	12	0.03	0.88	-0.24	0.31
OnLeash	Lakewood	35	-0.32	0.01	0.23	0.09
OnLeash	Loop 360	36	-0.38	0.01	0.33	0.01
OnLeash	Spicewood	17	-0.24	0.18	-0.19	0.35
OnLeash	Trib 2	16	-0.08	0.68	-0.03	0.89

Correlations with Air Temperature and Month

Water temperature is not measured continuously, but air temperature is a good surrogate for water temperature and may be related to the likelihood of park use. National Weather Service Austin average air temperature measurements were compared to *E. coli* measurements on the same day by Kendall's tau-b correlation analysis. In general, *E. coli* measures are directly related to air temperature values (Table 7), although there was a significant inverse relationship to temperature at the Lakewood site during the post-education period.

There is no clear pattern in average monthly *E. coli* geometric means at the Lakewood or Loop 360 sites (Figure 10). January yielded the lowest overall monthly geometric means at both sites. The Lakewood site may yield higher geometric mean *E. coli* during the spring and summer months although the Loop 360 site may yield higher summer geometric mean *E. coli* values.

Table 7. Results of Kendall's tau-B correlation of *E. coli* with average air temperature. Green shaded cells show significant correlation ($\alpha < 0.05$).

Period	Site	N	Temperature	
			Tau-b	Pr>= Tau
Historic	Loop 360	17	0.16	0.36
PostSpill	Lakewood	158	0.33	0.01
PostSpill	Loop 360	20	0.21	0.23
PostEducation	Lakewood	110	-0.30	0.01
PostEducation	Loop 360	96	0.13	0.06
PostEducation	Spicewood	10	-0.09	0.71
PostEducation	Trib 2	4	.	.
PreClosure	Lakewood	33	0.33	0.01
PreClosure	Loop 360	27	0.21	0.12
PreClosure	Spicewood	7	0.61	0.05
PreClosure	Trib 2	2	.	.
Closure	Lakewood	33	0.27	0.03
Closure	Loop 360	35	0.35	0.01
Closure	Spicewood	12	0.41	0.06
Closure	Trib 2	12	0.03	0.89
OnLeash	Lakewood	35	0.21	0.09
OnLeash	Loop 360	36	0.39	0.01
OnLeash	Spicewood	17	0.09	0.59
OnLeash	Trib 2	16	0.57	0.01
All data	Lakewood	370	0.03	0.34
All data	Loop 360	231	0.29	0.01
All data	Spicewood	46	0.01	0.92
All data	Trib 2	34	0.52	0.01

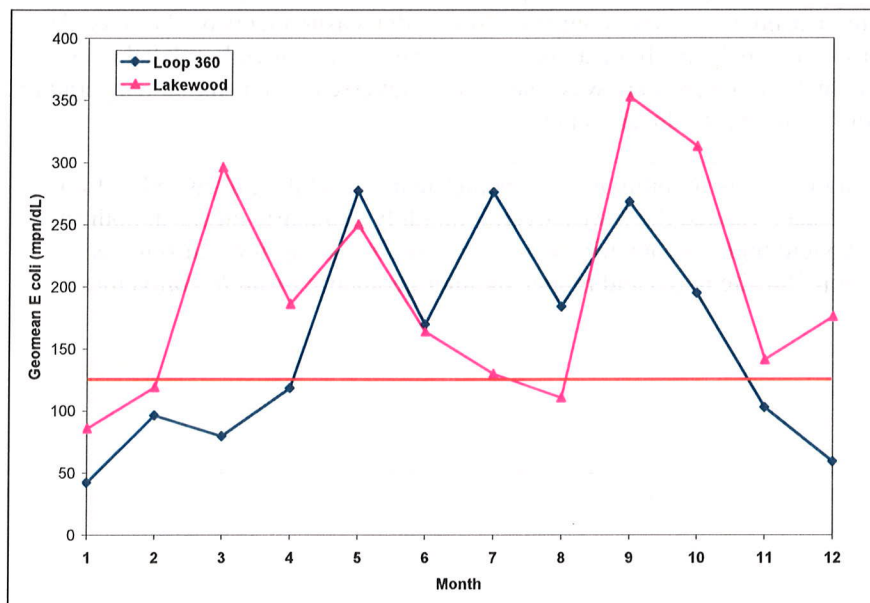


Figure 10. Monthly geometric mean *E. coli* for all data. The red line represents the Texas contact recreation standard of 126 mpn/dL.

Load Duration Curves

Load duration curves are recognized tools for non-point or point-source determination in Total Maximum Daily Load assessments (EPA 2007). Load duration curves characterize water quality under different flow regimes to visualize the frequency and magnitude of standard exceedances. Impairments observed under low flow regimes typically indicate point source impacts while impairments observed under high flow regimes typically indicate non-point source impacts. Load duration curves were calculated for the Lakewood (Figure 11) and Loop 360 (Figure 12) sites by following EPA methodology using the mean daily flows from the USGS flow gauge at Loop 360 (08154700) without including a margin of safety in the contact recreation standard as the curves are not being used for actual TMDL apportionment.

Exceedances of the standard occurred across the range of flow regimes at the Lakewood site, suggesting a combination of point and non-point source impacts. There are clear differences in the post-spill periods before education began between the Loop 360 and Lakewood sites, with few exceedances at Loop 360 but consistent exceedances at Lakewood. The post-spill, pre-education time period was consistent with historical monitoring at Loop 360. The reduction in bacteria levels during the on-leash period occurred primarily after the flooding of Tropical Storm Hermine (Figure 13).

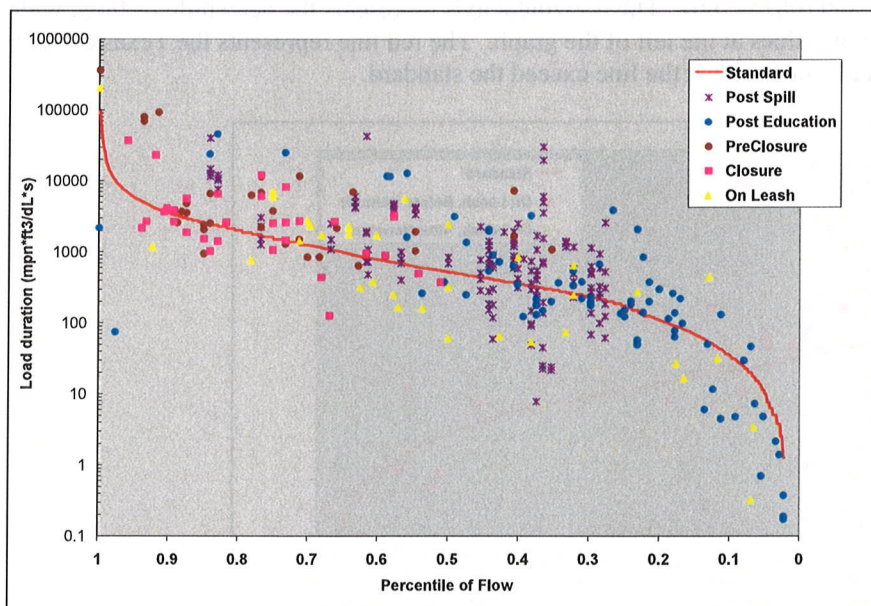


Figure 11. Load duration curve for the Lakewood site by time period calculated using mean daily flows from the USGS gauge at Loop 360 (08154700). The horizontal axis represents the percentile of flow, with the largest recorded flow values at the left of the graph. The red line represents the Texas contact recreation standard, and values above the line exceed the standard.

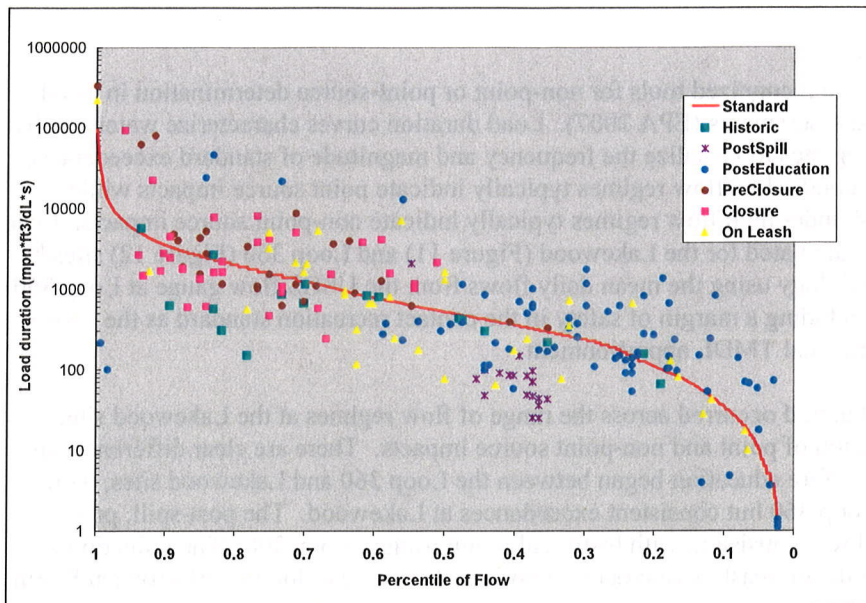


Figure 12. Load duration curve for the Loop 360 site by period using mean daily flows from the USGS gauge at Loop 360 (08154700). The horizontal axis represents the percentile of flow, with the largest recorded flow values at the left of the graph. The red line represents the Texas contact recreation standard, and values above the line exceed the standard.

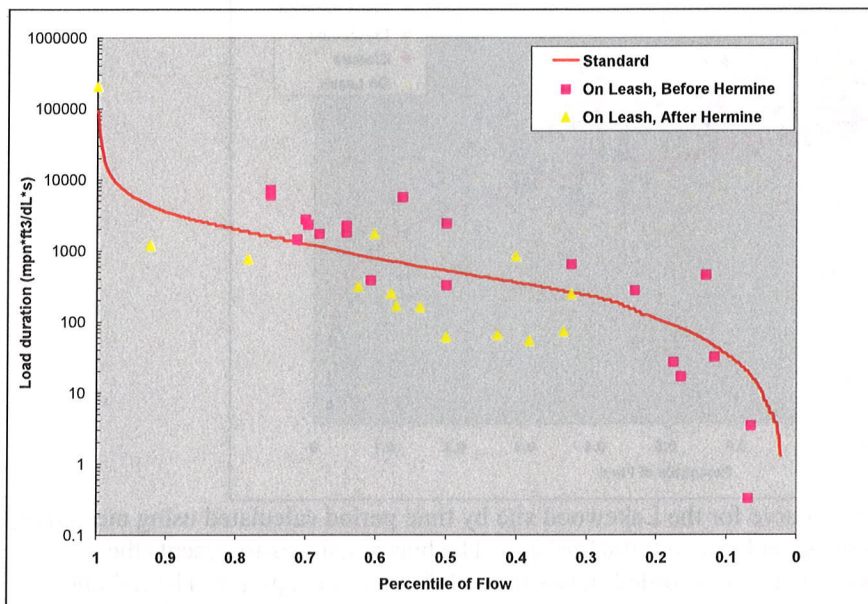


Figure 13. Load duration curve for the Lakewood site during the on-leash period with data separated before and after Tropical Storm Hermine. The horizontal axis represents the percentile of flow, with the largest recorded flow values at the left of the graph. The red line represents the Texas contact recreation standard, and values above the line exceed the standard.

Park Usage

The number of dogs (Figure 14) and people (Figure 15) present are counted instantaneously by WPD staff during weekend sampling events at the Loop 360 and Lakewood sites, typically performed in the early afternoon hours on a Sunday. There is no statistically significant

correlation with time by Kendall's tau-B analysis for the number of people or number of dogs present at the Loop 360 site for the period of record. There is a negative correlation of the number of dogs present ($\text{tau-B} = -0.32$, $n=48$, $\text{Pr}>\text{tau}=0.0019$) at the Lakewood site over time for the period of record, but no significant correlation with time in number of people present at the Lakewood site.

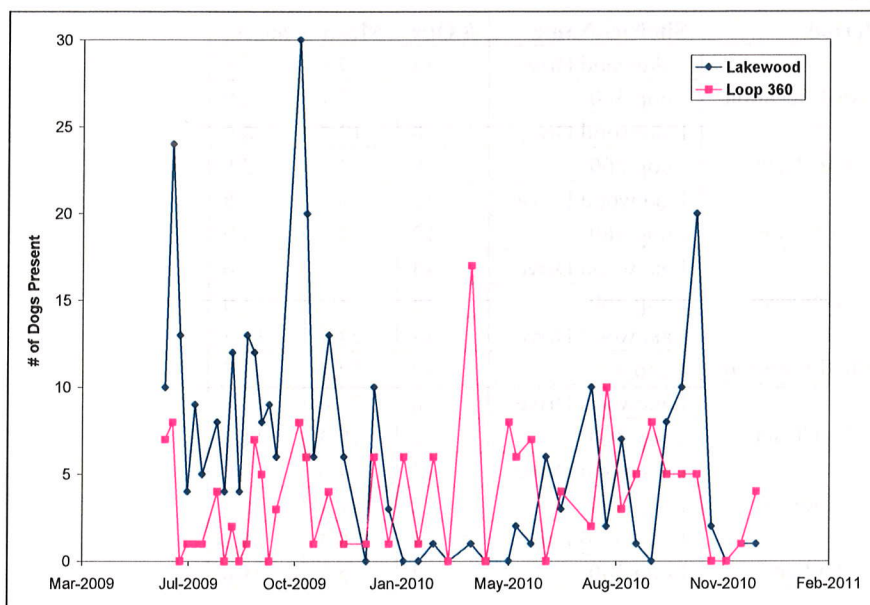


Figure 14. Number of dogs present at weekend sampling events.

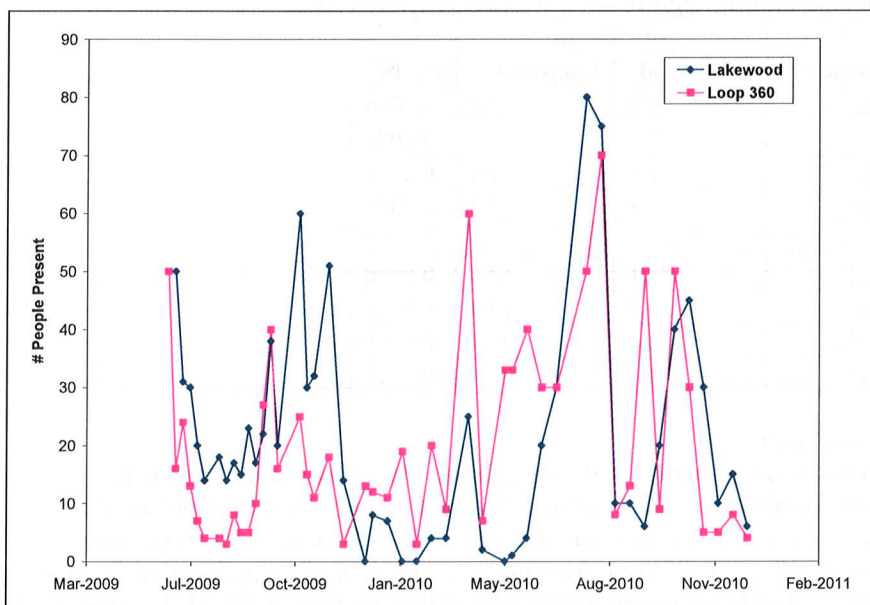


Figure 15. Number of people present at weekend sampling events.

The Lakewood site maintained significantly higher number of people and dogs than the Loop 360 site on average (Table 8) for the post-education and pre-closure period by Wilcoxon signed-rank test (Table 9). The Loop 360 site maintained significantly higher numbers of dogs than the Lakewood site during the closure period, and there is no significant difference in number of dogs

($Pr>|S|=0.51$) between sites during the on-leash period. Site differences in number of people present follow observed patterns with # of dogs. Number of people present may be increasing at the Loop 360 site over time.

Table 8. Number of observations, mean and standard deviation for number of people and dogs present by site and period.

Parameter	Period	SiteNickName	# Obs	Mean	Stdev
DOGS AT SITE	PostEducation	Lakewood Drive	14	9.6	5.3
		Loop 360	12	2.7	3.0
	PreClosure	Lakewood Drive	8	12.3	8.6
		Loop 360	8	3.5	2.8
	Closure	Lakewood Drive	12	1.5	2.8
		Loop 360	12	4.9	4.9
	OnLeash	Lakewood Drive	14	5.1	5.6
		Loop 360	14	3.7	3.0
	PostEducation	Lakewood Drive	14	24.1	12.2
		Loop 360	12	12.4	13.3
PEOPLE AT SITE	PreClosure	Lakewood Drive	8	33.4	15.8
		Loop 360	8	19.4	11.2
	Closure	Lakewood Drive	12	4.6	7.0
		Loop 360	12	21.7	16.7
	OnLeash	Lakewood Drive	14	28.4	24.2
		Loop 360	14	25.9	21.8

Table 9. Wilcoxon signed-rank test results for number of people and number of dogs present. $Pr>|S|$ values less than 0.05 indicate significant differences between sites.

Period	Parameter	Site Means		$Pr> S $
		Lakewood	Loop 360	
PostEducation	Dogs	9.6	2.7	0.0005
PreClosure	Dogs	12.3	3.5	0.0078
Closure	Dogs	1.5	4.9	0.0449
OnLeash	Dogs	5.1	3.7	0.5073
PostEducation	People	24.1	12.4	0.0010
PreClosure	People	33.4	19.4	0.0547
Closure	People	4.6	21.7	0.0005
OnLeash	People	28.4	25.9	0.3311

Nutrients from Bull Creek Study

WPD routinely monitors the water quality of the Bull Creek Watershed from a chemical perspective, and recently published a report summarizing that monitoring data (Duncan et al 2010). Ammonia, conductivity, aquatic vegetation coverage and dissolved oxygen values at the Loop 360 site were not significantly different from other upstream monitoring locations across the Bull Creek Watershed. The lack of substantially elevated ammonia, increased algae coverage, increase in conductivity or depressed dissolved oxygen do not support the hypothesis that on-going wastewater leakage is responsible for elevated indicator bacteria levels within the park. The Bull Creek Study (Duncan et al 2010) describes a recent increasing *E. coli* over time at the Loop 360 site, but does not describe any temporal trends in nutrient concentrations.

Weekend/Weekday

Previous analyses (COA 2008) noted a strong increase in *E. coli* concentrations on weekend days relative to weekdays, suggesting that park usage which is generally higher on weekends is correlated to indicator bacteria. The increased *E. coli* geometric mean on weekend pattern was maintained at the Lakewood site until the park was closed in December 2009 for restoration (Figure 16), although the difference in mean *E. coli* on weekends was only significant by the non-parametric Wilcoxon rank-sum test in the post-spill and post-education periods. A similar pattern of higher *E. coli* on weekends was never observed at the Loop 360 site (Figure 17). There is no significant difference by Wilcoxon rank-sum test between weekend and weekday *E. coli* at Loop 360 in any time period.

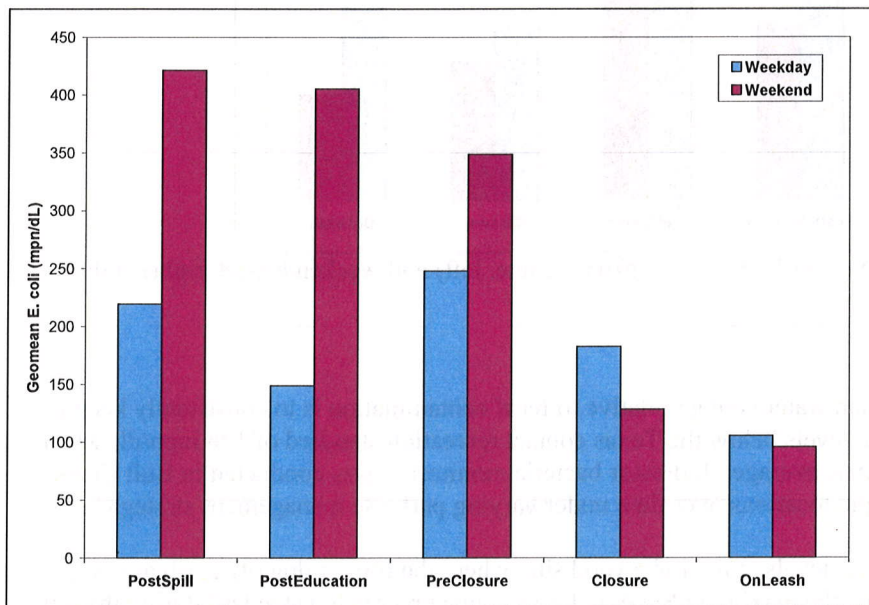


Figure 16. Geometric mean *E. coli* on weekdays (blue, left) and weekends (red, right) at the Lakewood site.

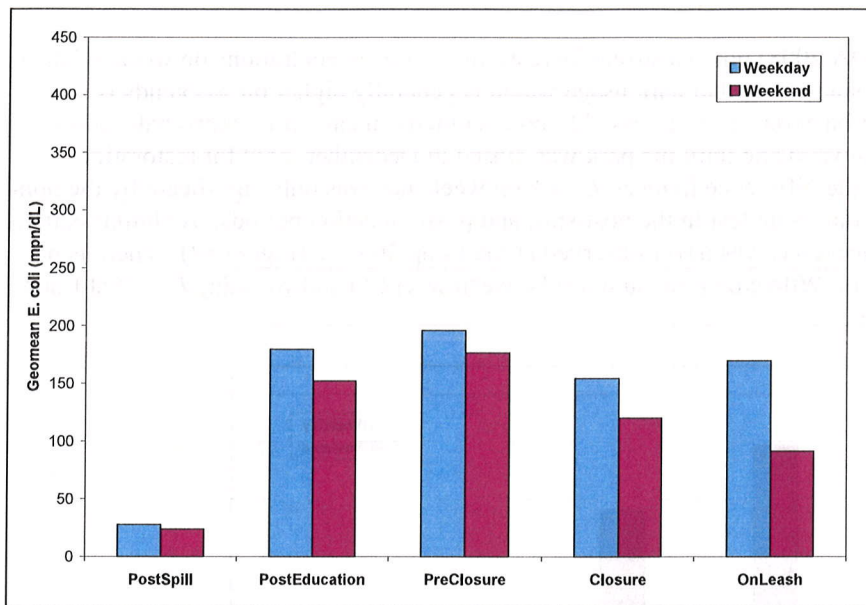


Figure 17. Geometric mean *E. coli* on weekdays (blue, left) and weekends (red, right) at the Loop 360 site.

Conclusions

The goal for safe human water contact relative to fecal contamination is to consistently keep *E. coli* indicator bacteria levels below the Texas contact recreation standard of 126 mpn/dL when calculated as a geometric average. Indicator bacteria monitoring was conducted in Bull Creek District Park at multiple locations over time under varying park use management strategies.

Average *E. coli* bacteria levels at the Lakewood site, where the former dog off-leash area was located, dropped below the maximum State of Texas contact recreation standard during the time period when dogs were allowed in the park on-leash only, although the decrease in this period primarily occurred following Tropical Storm Hermine. *E. coli* levels increased above the contact recreation standard at the Loop 360 site following the public education campaign initiated in March 2008 and remain above the contact recreation standard. The source of fecal contamination appears to be localized within Bull Creek District Park.

The public education campaign conducted in March 2008 did yield a measured improvement in public opinion but did not successfully lower bacteria levels below the Texas contact recreation standard. Volunteer efforts initiated in June 2008 did not successfully lower bacteria levels below the contact recreation standard. A physical restoration project was conducted in Bull Creek District Park near the Lakewood site while the park was closed from December 2009 to May 2010. The project was successfully completed on time and under budget, but did not lower bacteria levels below the contact recreation standard.

Genetic microbial source tracking conducted to date indicates that the fecal contamination is not of human origin, although additional validation of the method is required. Birds may be contributing fecal loads to Bull Creek particularly in April but are not responsible for increasing bacteria above contact recreation standards. Based on patterns in water chemistry, there is no evidence of on-going wastewater contamination of Bull Creek in the park. Contaminated sediments may be a reservoir for fecal bacteria although there is no spatial or temporal trend that would consistently explain the observed bacteria levels in water.

Based on load duration curves, there appears to be a mix of point and non-point sources of fecal contamination to Bull Creek. Usage by people may be increasing over time at the Loop 360 site while number of dogs present may be decreasing over time at the Lakewood site. Weekend *E. coli* concentrations remain significantly higher than weekdays at the Lakewood site thru the post-education period, suggesting a continued relationship between water column *E. coli* and park use. There was no difference in weekend and weekday bacteria levels at Loop 360.

Discussion and Recommendations

Until more specific and validated analytical methods become reasonably available, there will not be a determination that the fecal contamination is exclusively or primarily from dogs with a high degree of confidence. All indications suggest that the contamination is not from on-going leaking wastewater infrastructure, and genetic bacteria source testing conducted to date suggest the fecal contamination is of non-human origin. Most likely, there is a mix of fecal sources operating within Bull Creek District including non-point source fecal contributions from upstream areas, dog waste in the park and human usage that are interacting with instream sediments. Sediments may be acting as a reservoir for fecal bacteria that are re-suspended in the water column during recreation activities.

Genetic bacteria testing methods and applications are still in development, even on a national scale. Although genetic methods are appealing in similar situations where conflicting uses are in question, it is likely that the full application of these methods to the fecal source identification within Bull Creek could be several years away.

The increase observed at the Loop 360 site following the public education campaign may have been the result of overall increased usage of the park or creating a pattern of avoidance of the Lakewood area by some park users because of the increased signage there resulting in a transfer of use to Loop 360. The lack of an observed weekend/weekday pattern at the Loop 360 site may be a function of the geomorphology of that location, as that reach is more of a bedrock run with generally less sediment accumulation than the Lakewood site.

Remediation of fecal contamination where contact recreation is not supported is extremely challenging, as there are frequently uncontrollable sources like wildlife and a high degree of variability in bacteria measurements. Remediation efforts must control all known or probable fecal contamination sources to the maximum extent practical. Control of known fecal sources is the reasoning behind EPA policy recommendations (EPA 2001) and Texas Parks and Wildlife Department regulations (TPWD Code 59.134e) that restrict dogs from areas near human swimming locations.

It is likely that the combination of public education, volunteer activity, reduction in usage during the closure period, and physical restoration of the riparian areas reduced the fecal load to sediments in Bull Creek. Previously contaminated sediments were likely scoured away or buried by flooding from Tropical Storm Hermine. It is critical to maintain the reduction in fecal loadings to prevent sediments from becoming re-contaminated. If sediments become sufficiently re-contaminated by re-introduction of a fecal source, it is likely that contact recreation will not be supported even if that source is removed until another rare, large flooding event like Hermine occurs.

There is a range of signage posted within Bull Creek District Park currently, including both regularly updated postings of bacteria counts, swimming advisories, and educational signage on

the water quality impacts from uncollected dog waste. This signage should be revisited, consolidated and updated once the future management of the park has been determined.

The ultimate management decision for Bull Creek District Park rests with the Austin Parks and Recreation Department, and must take into consideration the protection of human health. There are a range of potential options available relative to Bull Creek water quality, including:

- Prohibit swimming in Bull Creek: A prohibition on swimming would not address a known potential human health concern and thus is inconsistent with the practices of the City of Austin and may pose inherent legal liability concerns as suggested by Law Department staff. This is also the removal of a popular park use and reduction in the resource value of Bull Creek inconsistent with the mission of the Watershed Protection Department which seeks to improve water quality.
- Prohibit dogs from Bull Creek District Park: Removal of dogs from Bull Creek would be easier to enforce than current “Scoop the Poop” regulations, although enforcement is limited by the available resources of the Austin Police Department. The removal of dogs would be a removal of a popular park use and may require a new City ordinance. Although the prohibition of dogs would most likely reduce fecal loading to Bull Creek relative to continued off-leash use, the prohibition may not be necessary now that contact recreation is supported.
- Evaluate a provisional return to off-leash use or allow off-leash only on weekdays: A provisional off-leash evaluation period with continued monitoring to verify that indicator bacteria levels do not increase is a logical approach. However, this strategy risks the re-contamination of sediments particularly if there is insufficient sustained volunteer engagement to assist the resource-limited Parks and Recreation Department with the maintenance of the park. A return to off-leash use may negatively impact restored areas, which may require some additional protection via fencing or additional maintenance until all vegetation is fully established. Weekday-only dog off-leash use has been suggested, and may be a solution to help reduce park uses but still inherently risks re-contaminating stream sediments. If sediments become re-contaminated, no management action is likely to reduce bacteria levels below contact recreation standards until a rare, large flood event like Hermine occurs.
- Create a smaller, fenced area for off-leash use at Bull Creek District Park: A smaller fenced area for off-leash use within lower Bull Creek District Park may help segregate some park uses and may keep intense dog activities further from the creek. Increased distance from the creek with healthy riparian buffers may reduce fecal contamination of Bull Creek during runoff events. Users within a fenced area may be more likely to collect dog waste because of the confines of the smaller area. Engineering controls could also be added to improve stormwater treatment. Dogs may still be a non-point source of fecal loading to the creek, and enforcement would be required to insure off-leash use is restricted to the fenced area only. Significant funding would need to be provided for the construction of this fenced area.
- Continue dog on-leash only use with continued educational outreach on the collection of pet waste: Dogs being allowed on-leash only maintains all current uses, although in a reduced capacity for dog-related uses. Although there is the same risk that sediments may be re-contaminated over time, the risk is likely lower with on-leash only use relative to off-leash use.
- Additional monitoring: Additional monitoring has the benefit of continuing to provide information that can increase understanding of the potential fecal sources, but additional monitoring in the near term as the sole management measure is only recommended if the

park remains on-leash only for dogs to fully evaluate the potential impacts of this management strategy for a longer period of time after Tropical Storm Hermine. Additional monitoring should be continued at Bull Creek District Park, regardless of the selected management strategy, although a lower frequency may be appropriate, to insure contact recreation use remains supported.

References

- City of Austin (COA). 2007. Lower Bull Creek District Park Contact Recreation Use Assessment. SR-08-02. 23 *pp*.
http://www.ci.austin.tx.us/watershed/publications/files/SR-08-02%20Bull_Contact_Rec.pdf
- Bae, S., and M. J. Kirsits. 2010. Technical memorandum for microbial source tracking studies to the City of Austin. 01/11/2010.
- Duncan, A., and H. Perry, A. Richter. 2010. Bull Creek Report Update, 2010. City of Austin Watershed Protection Department, Environmental Resource Management Division. SR-10-17. 31 *pp*.
- Sejkora, P., and M.J. Kirsits, R. Bashar, S. Bin-Shafique, M. Barrett. 2010. Bacteria Levels in Discharges from Road Right-of-Ways. The University of Texas at Austin Center for Transportation Report No 0-6147-1.
- Texas Commission on Environmental Quality (TCEQ). 2008. Guidance for assessing and reporting surface water quality in Texas.
- United States Environmental Protection Agency (EPA). 2001. Source Water Protection Practices Bulletin: Managing Pet and Wildlife Waste to Prevent Contamination of Drinking Water. EPA 916-F-01-027. 3 *pp*.
- United States Environmental Protection Agency (EPA). 2007. An approach for Using Load Duration Curves in the Development of TMDLs. Watershed Branch, Office of Wetlands, Oceans and Watersheds. EPA 841-B-07-006. 74 *pp*.
- Wagner, S., and M. Scoggins. 2010. Bacteria in sediment on Bull Creek. City of Austin Watershed Protection Department, Environmental Resource Management Division. SR-11-05. 9 *pp*.

