City of Austin
WATERSHED PROTECTION

Diel dissolved oxygen patterns and aquatic life use assessment.

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Diel dissolved oxygen (DO) data from 318 deployments at 38 stream sites were evaluated for spatial and temporal patterns and compared using TCEQ aquatic life use assessment DO criteria versus benthic macroinvertebrate aquatic life use categories. Diel DO data suggest that Austin streams generally maintain high or excellent aquatic life use potential. TCEQ assessment methods may not be appropriate for identifying aquatic life use impairments in some high quality Austin streams, and may yield impairments based on DO that are not observed in benthic macroinvertebrate data. Additional investigation of low DO in Bull Creek preserve lands is needed..

Introduction

The Texas Commission on Environmental Quality (TCEQ) has developed clear methods for the collection and evaluation of diel dissolved oxygen (DO) data (TCEQ 2009). Designated aquatic life uses are protected by an average and absolute minimum DO criteria, measured over the first consecutive 24-hours of a deployment. The aquatic life use (ALU) standard is not supported when these criteria are not attained in more than 10% of the samples. Dissolved oxygen criteria are derived from aquatic life use criteria (Table 1).

Unclassified perennial streams are presumed to have a high ALU standard. Unclassified intermittent streams with perennial pools are presumed to have a limited ALU standard in most cases. Intermittent streams without perennial pools are presumed to have minimal ALU. The majority of streams in Austin are presumed to be at least intermittent with perennial pools but have been designated as having high ALU.

Table 1. Aquatic life use and typical corresponding DO criteria. Criteria may be adjusted on a site-specific basis.

Aquatic Life Use	Typically Designated Average DO (mg/L)	Typically Designated Minimum DO (mg/L)
Exceptional	6.0	4.0
High	5.0	3.0
Intermediate	4.0	3.0
Limited	3.0	2.0
Minimal	2.0	1.5

Aquatic life use is also assessed directly by evaluation of the benthic macroinvertebrate community. The qualitatitve TCEQ aquatic life use score may be calculated and compared to a set of values (TCEQ 2009) to identify any impairment of the benthic community.

TCEQ guidance specifies that 24-hour DO measurements must be taken at the surface and when stream flows are above the 7Q2 (minimum 7-day low flow with a 2-year return probability, assumed to be 0.1 ft^3/s if the 7Q2 is not known). Current assessment methods (TCEQ 2010) require at least ½ of the samples be completed within the index period (March 15-October 15), and ¼ to $^1/_3$ of samples be completed within the critical period (July 1-September 30). Deployments must be separated by at least one month, and recommendations for future guidance include specifications that at least $^1/_3$ of samples be completed outside the index period to encourage year-round sampling. Previous assessment methods excluded non-index samples.

Aquatic life use impairments are listed on the 303(d) list of impaired water bodies. As of 2010, there is only one DO impairment in Austin streams in upper Bull Creek (segment 1403A_05). There are three Austin streams listed as "of concern" for DO impairments: Slaughter Creek (segment 1427A_01), Waller Creek from the mouth upstream to MLK (segment 1429C_01), and Barton Creek from SH71 upstream to the Hays County line (1430_04).

The City of Austin (COA) previously deployed datasondes for generally one month intervals in Barton Creek at the Lost Creek Boulevard and Barton Creek Boulevard sites from 1998 to 2004 (COA 2004). Extensive analysis determined that Barton Creek was fully supporting it's designated aquatic life use, baseline patterns in Barton Creek were well documented by this dataset, there were no temporal trends for the time period assessed, and the longer periods of deployment increased probability of calibration verification failures (COA 2004)

Methods

Data from 318 deployments at 38 stream sites were assessed. Deployments from lakes and groundwater springs (e.g., Barton Springs) were not assessed in this analysis and are addressed separately in other reports. Ten sites were sampled in relation to sanitary sewer overflows.

Sampling was conducted in the Barton, Bull, Onion, Walnut and Gilleland creek watersheds for routine sampling, and in the Blunn, Bull and Williamson creek watersheds for the sewage spill investigations. The Gilleland Creek watershed is the only sampled watershed receiving any treated wastewater effluent discharges. All watersheds sampled for routine monitoring are presumed to have high aquatic life use. Sites immediately downstream and following sewage spills might represent worst case conditions with maximum oxygen demand due to high content of oxygen-demand organic matter from the sewage.

Diel (24-hour) averages and minimum statistics were calculated following TCEQ specifications, using the first 24-hours of deployment. Water chemistry results as well as benthic macroinvertebrate and periphyton (diatom) biological metrics for temporally relevant samples were associated with the individual deployments. Benthic macroinvertebrates were evaluated based on the TCEQ qualitative aquatic life use score, and diatom samples were evaluated based on average pollution tolerance index values and percent similarity to reference condition sites.

Incomplete deployments (< 24 hours) or deployments failing post-deployment calibration verification were excluded from the analysis. All deployments recorded at least hourly measurements, and the majority of deployments recorded at 15-minute intervals. In addition to DO, diel maximum and minimum pH and maximum temperature were compared to TCEQ criteria using site-specific values typical of classified segments in the Austin area.

Results

There were no exceedances of minimum (<6.5) or maximum (>9.0) pH criteria in any deployment. The minimum measured pH value was 6.75, and the maximum measured pH value was 8.93.

There were very few exceedances of maximum temperature (>90ºF, 32.2ºC). Only three deployments yielded absolute maximums above criteria, and these exceedances do not represent impairments based on the number of samples not exceeding the temperature maximum (Table 2).

Table 2. Deployments exceeding maximum temperature criteria (32.2 ºC). Temperature values in ºC.

Start Date	Site #	Site Name	Max Temp	Min Temp	Avg Temp
07/27/99	82	Barton Creek Dwnstrm of Barton Creek Blvd	32.20	28.30	29.80
07/06/05	236	Onion Creek @ Twin Creeks Road	32.44	26.63	29.36
07/25/01	51	Barton Creek Downstream of Lost Creek Blvd	32.66	29.87	31.20

TCEQ assessments for DO impairments are based on the 10% exceedances of the criteria (following the binomial method) and are conducted ideally on at least 10 samples but may be conducted on as few as 4 samples. Following TCEQ protocol, the worst case of the average and minimum was assessed for each site based on the lower 10^{th} percentile. For the 27 routine monitoring sites (Table 3), all sites except 1 had at least 4 measurements. Based on the lower 10^{th} percentile, 8 sites would be classified as excellent ALU, and 6 sites would be classified as high ALU following TCEQ assessment methods. The 2 effluent dominated sites on Gilleland were classified as high (Gilleland at S. RR Ave) and excellent (Gilleland at FM 969), despite yielding the highest ambient nutrient concentrations. No routine site on Walnut was classified as high ALU, with the headwater and mouth sites yielding minimal ALU while the 2 mid-reach sites yielded intermediate ALU. In total 12 of 26 (46%) sites would not meet TCEQ ALU criteria and would be classified as impaired for DO. The 2 reference condition sites on Bull Creek (#920 Bull Creek at St. Ed's Park and #349 Bull Creek Tributary 7 at Franklin Tract) yield minimal and limited ALU, respectively. Barton Creek at SH71, another reference condition site, also yielded minimal ALU. However, all routine monitoring sites assessed yielded at least 50% of measurements in the excellent or high ALU categories. The low (<10) number of samples strongly influences the assessment of data. For example, of the 7 measurements from Barton Creek at SH71, 6 samples are excellent and only 1 is limited although using the 10^{th} percentile method this site would at least be designated as "of concern" if not impaired for DO.

Table 3. Lower 10th percentile classification, with # measures per time period, sorted by ascending ALU classification based on diel DO.

#	Site	First	Last	Critical	Index	NonIndex	Lower 10th %
46	Barton Creek @ Shield Ranch Pool	2007	2009	1	2	1	Exceptional
51	Barton Creek Downstream of Lost Creek Blvd	1998	2009	13	23	22	Exceptional
82	Barton Creek Dwnstrm of Barton Creek Blvd (BC4)	1998	2004	9	19	20	Exceptional
3974	Bull Creek Above WTP4	2007	2007	2	1	3	Exceptional
3975	Bull Creek Below WTP4	2006	2007	1	0	3	Exceptional
3977	Bull Creek Tributary 8 Upstream of Bull Creek	2007	2007	2	1	2	Exceptional
886	Gilleland Creek @ FM 969	2008	2009	0	3	1	Exceptional
612	Onion Creek near Driftwood (Hwy 150)	2004	2009	3	4	1	Exceptional
50	Barton Creek @ Leif Johnson Pool	2006	2009	3	3	1	High
44	Barton Creek @ Stark Pool	2007	2009	1	2	1	High
1193	Gilleland Creek @ South Railroad Avenue	2008	2009	0	3	1	High
1366	Onion Creek @ South Austin Regional WWTP (SAR)	2004	2009	4	4	1	High
241	Onion Creek Above Footbridge (OC3)	2006	2009	3	3	1	High
151	Tributary 6 @ Bull Creek (EG)	2006	2009	2	4	1	High
2954	Barton Creek @ Nature Conservancy Headquarters	1998	1999	2	5	5	Intermediate
1365	Onion Creek at Pfulman Ranch	2004	2008	4	4	0	Intermediate
502	Walnut Creek @ Old Manor Road	2005	2009	4	3	1	Intermediate
464	Walnut Creek Below IH35	2006	2009	3	3	1	Intermediate
48	Barton Creek @ Hwy 71 Below Little Barton	2006	2009	3	3	1	Limited
349	Bull Creek Above Tributary 7 (Franklin)	2004	2009	7	4	3	Limited
255	Onion Creek @ McKinney Falls Below Lower Falls	2004	2009	5	4	1	Limited
236	Onion Creek @ Twin Creeks Road (OC1)	2004	2009	6	4	1	Limited
920	Bull Creek @ St. Edwards Park above dam	2005	2009	3	4	1	Minimal
1164	Tributary 5 Below Hanks Tract Property Line	2005	2009	2	4	2	Minimal
895	Walnut Creek @ Metric Blvd	2006	2008	3	1	0	Minimal
503	Walnut Creek Above SP Railroad Bridge	2007	2009	2	1	1	Minimal

Based on the average and median of the 24-hour average DO and 24-hour absolute minimum DO for the same set of 26 routine monitoring sites yields dramatically different results (Table 4). No site yields an average or median 24-hour average DO value less than 5 (high), and only 3 sites yield median or average 24-hour DO average values less than 6 (excellent). Based on average 24-hour minimum DO, only 2 sites yield less than excellent ALU (but still in the high category). Based on median 24-hour minimum DO, only 1 site yields less than excellent ALU. Again, Bull Creek headwater areas appear to yield lowest DO.

Table 4. Mean and median of the 24-hour average DO and 24-hour absolute minimum DO for routine monitoring sites using all data, sorted by average 24-hour average DO. Yellow cells highlight impairments.

#	Site	N	24-hour Average		24-hour Minimum	
			Mean	Median	Mean	Median
349	Bull Creek Above Tributary 7 (Franklin)	14	5.10	5.03	4.71	4.77
1164	Tributary 5 Below Hanks Tract Property Line	8	5.63	5.39	3.97	2.81
895	Walnut Creek @ Metric Blvd	4	5.71	6.77	3.93	4.64
920	Bull Creek @ St. Edwards Park above dam	8	6.14	6.69	4.92	5.42
502	Walnut Creek @ Old Manor Road	8	6.42	6.68	5.11	4.35
50	Barton Creek @ Leif Johnson Pool	7	6.59	6.30	5.35	4.66
236	Onion Creek @ Twin Creeks Road (OC1)	11	6.60	6.85	4.70	4.98
2954	Barton Creek @ Nature Conservancy Headquarters	12	6.70	6.66	6.00	6.32
1365	Onion Creek at Pfulman Ranch	8	6.87	6.59	5.79	5.50
255	Onion Creek @ McKinney Falls Below Lower Falls	10	6.92	7.37	5.53	6.17
241	Onion Creek Above Footbridge (OC3)	7	7.02	7.01	5.74	5.67
1193	Gilleland Creek @ South Railroad Avenue	4	7.15	7.35	6.37	6.61
151	Tributary 6 @ Bull Creek (EG)	7	7.34	6.97	5.76	5.18
48	Barton Creek @ Hwy 71 Below Little Barton	7	7.37	8.03	6.55	7.18
464	Walnut Creek Below IH35	7	7.49	7.39	5.28	4.63
612	Onion Creek near Driftwood (Hwy 150)	8	7.55	7.62	7.10	7.28
1366	Onion Creek @ South Austin Regional WWTP (SAR)	9	7.58	7.61	6.33	6.30
3975	Bull Creek Below WTP4	4	7.58	7.61	7.24	7.15
46	Barton Creek @ Shield Ranch Pool	4	7.66	7.27	7.15	6.77
44	Barton Creek @ Stark Pool	4	7.75	8.09	6.65	7.32
3977	Bull Creek Tributary 8 Upstream of Bull Creek	5	7.77	7.73	7.34	7.38
3974	Bull Creek Above WTP4	6	7.82	7.84	7.34	7.38
886	Gilleland Creek @ FM 969	4	8.28	8.50	7.95	8.05
82	Barton Creek Dwnstrm of Barton Creek Blvd (BC4)	48	8.42	8.36	7.34	7.66
51	Barton Creek Downstream of Lost Creek Blvd	58	8.55	8.15	6.82	6.83
503	Walnut Creek Above SP Railroad Bridge	4	8.94	8.52	7.22	8.20

Aquatic life use determinations from matching (concurrent) benthic macroinvertebrate sampling and DO deployments were compared. In 19 of 24 (79%) sites with both diel data and benthic macroinvertebrate sampling, ALU determinations from average diel measurements were higher than ALU determinations from bugs, with 37% of DO deployments yielding “excellent” ALU when the benthic macroinvertebrate scores yielded only intermediate ALU (Table 5). Agreement between average DO and ALU was found in only 16% of sites, and only one site (349 – Bull Creek Tributary 7 at Franklin Tract) yielded better benthic macroinvertebrate ALU than DO ALU classification. The upper Bull Creek site appears to be one of the most degraded DO sites but yields high ALU based on benthic macroinvertebrate scores. Comparison of biological ALU to TCEQ assessment procedures suggests an impairment would be identified based on diel data in 46% of sites, and an impairment would not be identified in 42% of sites. There is little agreement between sites. However, diel fluctuations may not be solely responsible or corollary to biological degradation particularly in cases where biological degradation is due to hydrologic shifts.

Table 5. Comparison of ALU determination from concurrent biological and diel sampling, based on average diel measurements, TCEQ benthic ALU score, and based on TCEQ 10th percentile assessment methods.

#	Site	ALU from avg diel DO	ALU from benthic community	ALU from TCEQ assessment
48	Barton Creek @ Hwy 71 Below Little Barton	High	High	Limited
50	Barton Creek @ Leif Johnson Pool	High	High	High
895	Walnut Creek @ Metric Blvd	High	High	Minimal
920	Bull Creek @ St. Edwards Park above dam	High	High	Minimal
44	Barton Creek @ Stark Pool	Excellent	Intermediate	High
46	Barton Creek @ Shield Ranch Pool	Excellent	High	Exceptional
51	Barton Creek Downstream of Lost Creek Blvd	Excellent	High	Exceptional
151	Tributary 6 @ Bull Creek (EG)	Excellent	Intermediate	High
236	Onion Creek @ Twin Creeks Road (OC1)	Excellent	High	Limited
241	Onion Creek Above Footbridge (OC3)	Excellent	High	High
255	Onion Creek @ McKinney Falls Below Lower Falls	Excellent	High	Limited
464	Walnut Creek Below IH35	Excellent	High	Intermediate
502	Walnut Creek @ Old Manor Road	Excellent	High	Intermediate
503	Walnut Creek Above SP Railroad Bridge	Excellent	Intermediate	Minimal
612	Onion Creek near Driftwood (Hwy 150)	Excellent	High	Exceptional
886	Gilleland Creek @ FM 969	Excellent	Intermediate	Exceptional
1164	Tributary 5 Below Hanks Tract Property Line	Excellent	Intermediate	Minimal
1193	Gilleland Creek @ South Railroad Avenue	High	Intermediate	High
1365	Onion Creek at Pfulman Ranch	Excellent	High	Intermediate
1366	Onion Creek @ South Austin Regional WWTP (SAR)	Excellent	High	High
3974	Bull Creek Above WTP4	Excellent	Intermediate	Exceptional
3975	Bull Creek Below WTP4	Excellent	Intermediate	Exceptional
3977	Bull Creek Tributary 8 Upstream of Bull Creek	Excellent	Intermediate	Exceptional
349	Bull Creek Above Tributary 7 (Franklin)	Intermediate	High	Limited

Correlation of 24-hour average DO, 24-hour minimum DO, DO range and DO percent of saturation (%Sat) range were assessed by Kendall's tau-β (Brown and Benedetti 1977) with all other variables (Table 6). Few statistically significant correlations were observed for covariates tested. There was no statistically significant correlation between the DO parameters and the TCEQ benthic qualitative score, even when assessed as a partial correlation with season. There was no correlation between DO parameters and diatom metrics. There was no correlation between orthophosphorus or bacteria, but some correlation with nitrogen and TSS. In general, significant correlations were weak with maximum absolute correlation coefficient observed less than 0.30 for any comparison. Results from correlation with ammonia and nitrate are somewhat inconsistent. While ammonia follows expected inverse relationships with DO, nitrate is directly related although this may be a function of nutrient enrichment enhancing aquatic plant communities thereby increasing DO but not to such an extent that plant respiration exerts a significant oxygen demand.

Table 6. Kendall's tau-β correlation coefficients and associated pr>|r| for parameters yielding significant correlations with DO. The range is defined as the difference between the absolute maximum and minimum for a given deployment.

with…	# Obs	avg DO	min DO	DO range	DO %Sat range
Conductivity range	318	-0.089 p=0.02	-0.156 p<0.01	0.281 p<0.01	0.281 p<0.01
pH range	318	-0.136 p<0.01	-0.259 p<0.01	0.394 p<0.01	0.401 p<0.01
Ammonia	100	-0.066 p=0.35	-0.190 p<0.01	0.300 p<0.01	0.302 p<0.01
Nitrate	100	0.211 p<0.01	0.186 p<0.01	0.035 p=0.61	0.029 p=0.67
TSS	100	0.005 p=0.95	-0.022 p=0.75	0.147 p=0.03	0.151 p=0.03

Non-parametric Wilcoxon signed-rank (Gilbert 1987) matched pairs (by site) was used to evaluate differences between seasons using average 24-hour average and minimum DO by site (Table 7). Pairing by site removes some of the spatial variability, but does not account for temporal variability other than long-term seasonality. Significant differences were found between seasons, generally correlating with expected differences based on nominal temperatures and consistent with previous analyses (COA 2004). Minimal differences are observed between critical and index periods, although significantly higher DO values are observed in the winter non-index period. It would appear that the inclusion of non-index period sampling by TCEQ in DO assessments would reduce the number of impairments identified, and reflects a shifting focus from critical temperature conditions to more annually representative conditions.

Table 7. Wilcoxon signed rank test results. Pr>|S| values given, with average difference between seasons ± 1 standard deviation.

Parameter (n=23, results in mg/L)	Critical vs. Index	Index vs. Non-Index	Non-Index vs. Critical
24-hour average DO	p = 0.0886 +0.46 (±1.3) in Index	p < 0.0001 +1.4 (±1.2) in Non-Index	p < 0.0001 +2.4 (±1.4) in Non-Index
24-hour minimum DO	p = 0.0531 +0.38 (±1.2) in Index	p < 0.0001 +2.1 (±1.4) in Non-Index	p < 0.0001 +1.8 (±1.2) in Non-Index

Longitudinal differences between sites within a watershed were assessed over a consistent time period, 2004 to 2009 (figure 1) based on all available deployments. Barton Creek sites yield a generally consistent longitudinal trend. Bull Creek yields two groupings of site, with lower average DO generally observed at Tributary 5, Above Tributary 7 (Franklin) and at St. Edwards Park. Onion Creek yields fairly consistent site trends, with some increased variability at the most upstream site, Pfluman, and in the mid-reach at Twin Creeks Road. Walnut Creek yields an unusual trend, with longitudinal improvement in average diel DO from more developed headwaters to less developed conditions near the mouth.

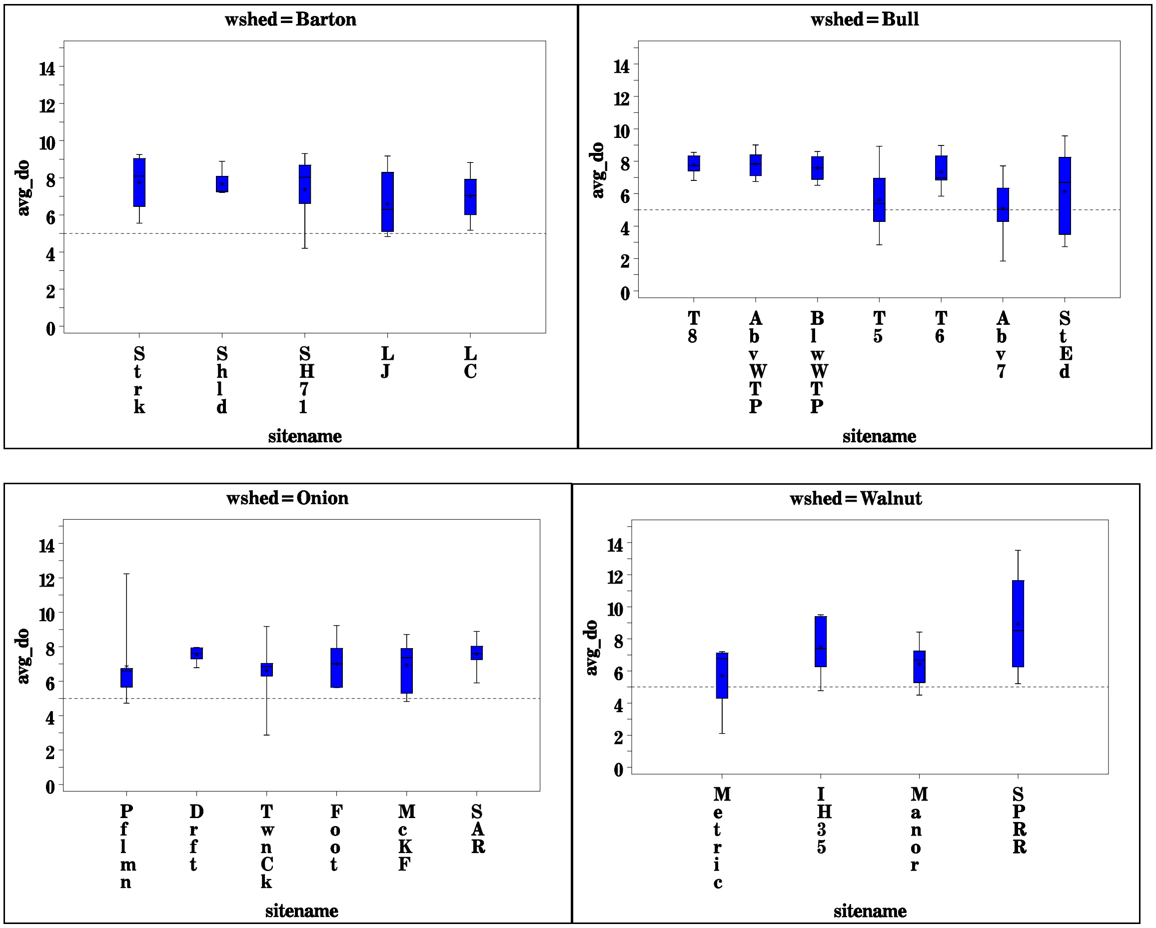

Figure 1. Summary of average DO (mg/L) measurements by site and watershed from 2004 to 2009. Sites by watershed, in upstream to downstream order, left to right. The vertical reference line indicates 5 mg/L.

Temporal trends by site were assessed using Kendall's tau-β correlation with sample date for all routine monitoring sites with more than 3 measurements. Only 3 sites yielded any statistically significant correlation with time (Table 8). Minimum DO may be decreasing over time at Barton at Lost Creek. The range of DO may be decreasing over time for Bull Creek above Tributary 7 and Gilleland Creek at FM969.

Table 8. Kendall's tau-β correlation coefficients by parameter with sample date. Significant correlations highlighted in yellow.

Site #	Site Name	#	Avg DO	Min DO	DO Range	DO %Sat Range
51	Barton Creek Downstream of Lost Creek Blvd	58	-0.090	-0.183	0.075	0.080
349	Bull Creek Above Tributary 7 (Franklin)	14	0.099	0.121	-0.552	-0.538
886	Gilleland Creek @ FM 969	4	-0.333	0.000	-1.000	-1.000

Three substantial sanitary sewer overflows in different watersheds were sampled at the location of the overflow, and upstream and downstream of the spill, over a two month time period (Figure 2). Blunn Creek shows degradation in average and minimum DO immediately following the spill, but no substantial difference in the following weeks between the above and at spill locations, and no decreases below the high ALU criteria. Despite the influx of untreated domestic sewage, the recovery of Blunn Creek from a DO perspective appears to have occurred within 1 week of the spill. Stillhouse Hollow in Bull Creek appears to yield no degradation at the time of the spill and mixed results over time even at the control site upstream of the spill. Williamson Creek does exhibit the expected pattern of significant degradation at and downstream of the spill with a significant change in ALU classification. Recovery at the spill location on Williamson creek does not appear to occur over the 9 nine week period, although recovery downstream of the spill occurs within 3 to 5 weeks.

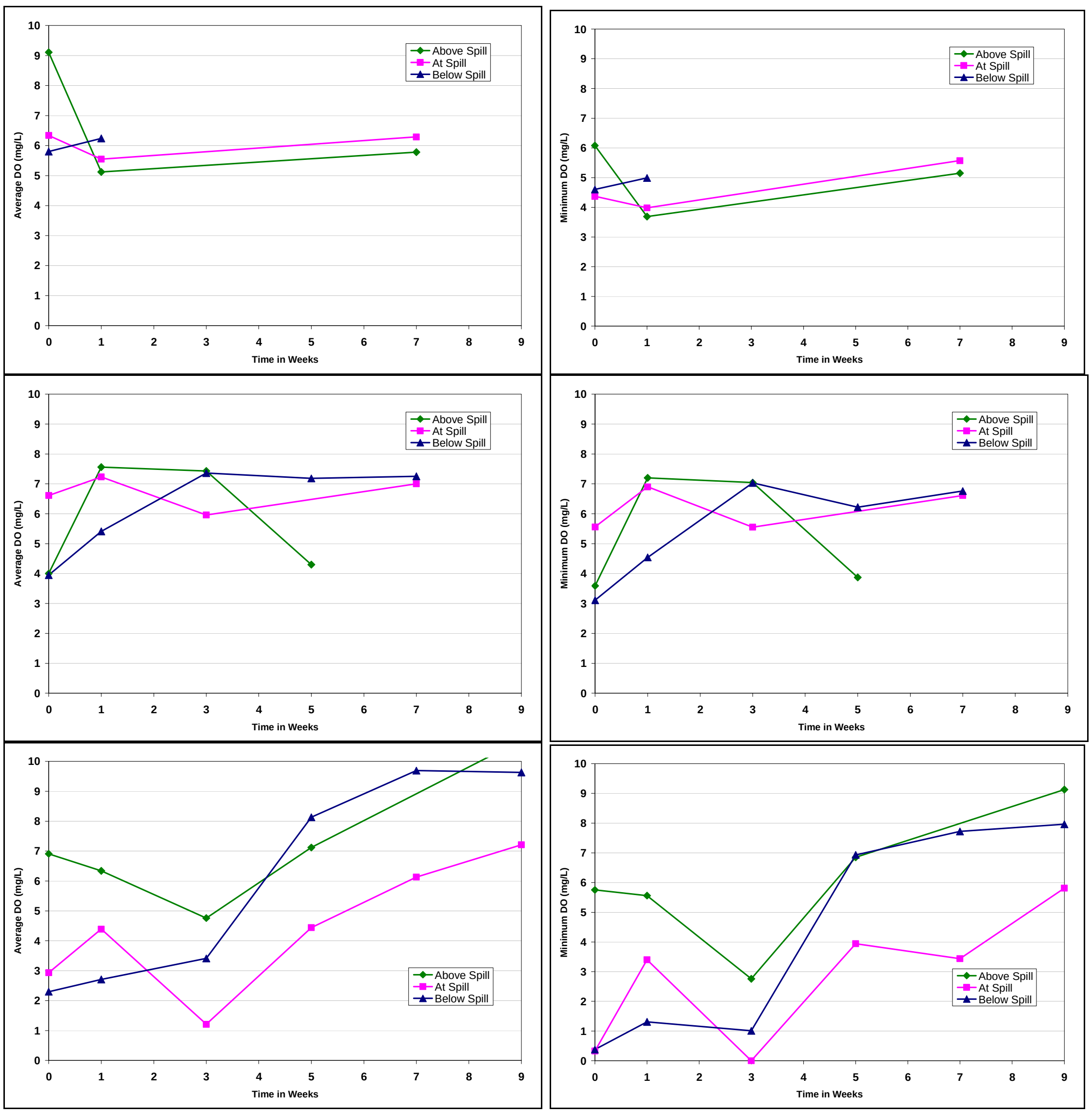

Figure 2. 24-hour average (left column) and absolute minimum (right column) DO following sewage spills in three watersheds. DO values in mg/L. Blunn Creek, top row. Stillhouse Hollow in Bull Creek, second row.

Conclusions

Diel DO when evaluated by site averages indicates that routine monitoring streams in Austin, including those that are effluent dominated, generally maintain high or excellent aquatic life use potential as defined by TCEQ guidance.

The lack of consistent, expected diel DO impacts in effluent-dominated streams or following domestic sewage overflows suggests DO may not be best indicator of degradation in Austin's creeks. However, the differences in longitudinal patterns of DO, particularly in Bull Creek and in Walnut Creek, may reflect localized impacts and need further investigation.

Diel DO measurements when assessed by TCEQ methods may yield an unacceptably large proportion of identified aquatic life use impairments when no impairment is supported by direct monitoring of the benthic community. Because biological data is not being submitted to TCEQ from the COA routinely, careful consideration should be used when deciding which diel DO sites should be submitted to TCEQ.

There is little correlation between biological measures and diel DO, suggesting that traditional DO degradation of streams from excessive organic matter loading or eutrophication may not be advanced enough in Austin to significantly impair benthic communities. There appears to be little change in diel DO over time at the majority of sites.

Seasonal differences may be important between index and non-index period sampling, but may not be important between index and critical period samples. However, any future submittals of diel data to TCEQ should consider the future recommendations incorporating non-index period samples.

Potential DO impairments in Bull Creek on the Franklin Tract and Walnut Creek at Metric suggest that some additional investigation at these locations may be warranted. Strong groundwater influences in Bull Creek may be affecting DO concentrations there, and based on elevated bacteria levels there is a potential for leaking wastewater infrastructure in Walnut Creek at Metric.

References

City of Austin (COA). 2004. Results from Continuous Monitoring of Barton Creek (1998-2004). City of Austin Watershed Protection Department, Environmental Resource Management Division, Water Resource Evaluation Section. SR-04-01.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, New York.

Brown, M.B., and J.K. Benedetti, J.K. 1977. Sampling Behavior of Tests for Correlation in Two-Way Contingency Tables. Journal of the American Statistical Association, 72: 309 - 315.

Texas Commission on Environmental Quality (TCEQ). 2009. DRAFT 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas. http://www.tceq.state.tx.us/assets/public/compliance/monops/water/10twqi/2010_guidance.pdf