RESULTS FROM CONTINUOUS MONITORING OF BARTON CREEK (1998-2004)

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Two Hydrolab^{TM} Datasonde 4 instruments were deployed on Barton Creek at the Lost Creek and Barton Creek (Fin Bridge) Boulevard locations taking generally continuous measurements at 15-minute intervals from 1998 to 2004 for dissolved oxygen (DO), temperature, conductivity, pH, depth and turbidity. Data were assessed to determine spatial, temporal, climatic and seasonal variation in addition to evaluation of quality of these long-term datasonde deployment results. Temperature and water depth show two seasonal groups with winter from November to March and Summer from May to September, with April and October forming the transitional periods. Lost Creek maintains higher monthly mean conductivity all year long and generally higher mean turbidity, suggesting a potential impact from the development located between the two sites. Higher DO values at Lost Creek may be the result of an increased algal community supported by a higher nutrient load than is available at Fin Bridge. Temperature and conductivity are negatively related to flow. Depth, pH and DO are positively related to flow. Groundwater influences may be more evident at the Lost Creek site based on pH and conductivity fluctuations with flow. No strong patterns of correlation with antecedent rainfall where observed.

As expected, conductivity decreases following storm events while pH and turbidity increase. DO appears generally unaffected by storm flow. Response of temperature to rainfall events depends on time of year, but generally decreases with rainfall. No clear temporal trends are evident, though 2000 was yielded the poorest water quality of all years studied. Comparison of continuous monitoring data to TCEQ water quality standards indicate that Barton Creek was not of concern for temperature, pH, conductivity (as a surrogate for TDS), or dissolved oxygen from 1998 to 2003. Turbidity is of extremely questionable accuracy when datasonde instrumentation are compared to concurrent instantaneous field measurements. As deployment length increases, datasonde sensors may drift out of calibration or become more inaccurate even though the percent change in daily mean values decreases toward zero. The study was useful in identifying short term responses to storm events and a variety of temporal changes in water chemistry at the sites; however, the significant investment in maintenance time resulted in conclusion of the study and diversion of surface water monitoring staff resources elsewhere. Alternatives for redeployment are provided for evaluation in future monitoring budgets.

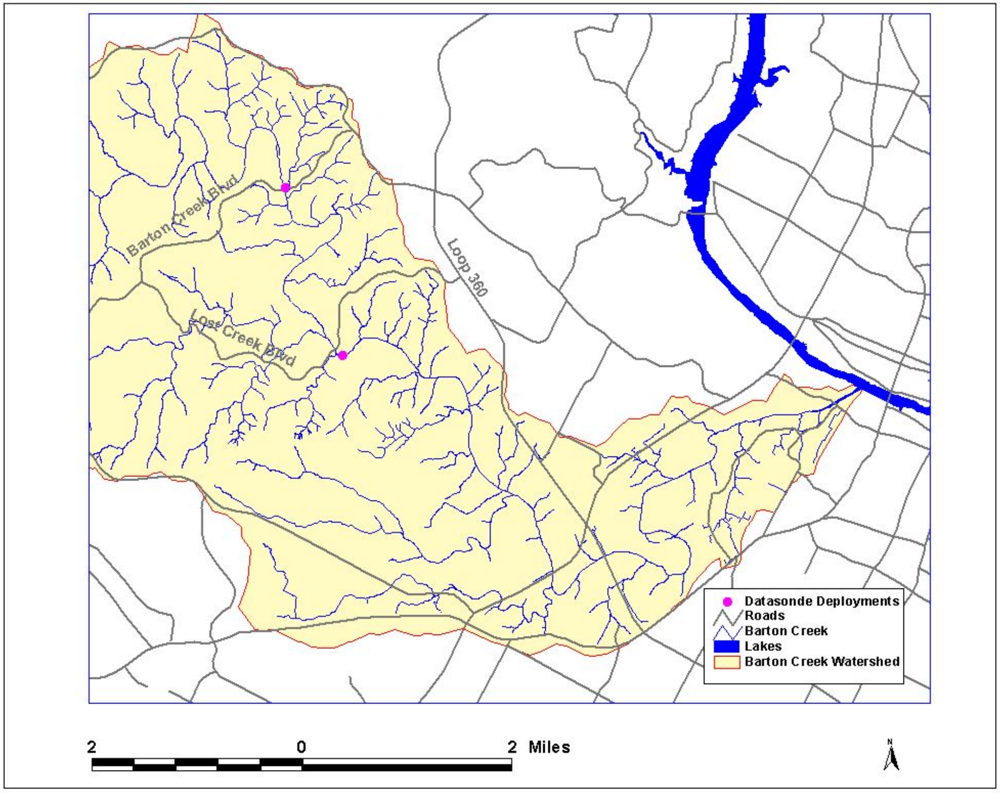
Introduction

As part of a response to a Austin City Council request for more continuous water quality monitoring of Barton Creek, Hydrolab^{TM} DataSonde 4 instruments were deployed at the Barton Creek Boulevard (also known as Fin Bridge) and Lost Creek Boulevard bridges over Barton Creek (Map 1) from October 1998 through February 2004 (see Appendix for complete inventory). Collecting data on pH, turbidity (NTU), conductivity, dissolved oxygen (DO) and depth below water surface generally at 15-minute intervals, this extremely robust dataset comprises approximately 130,000 measurements of each parameter per site.

Although the two deployment locations are within approximately 2.7 river miles from one another, the more downstream Lost Creek site receives drainage from an additional 5,000 acres (yielding a total drainage area of approximately 69,000 acres at the Lost Creek site). Land use differences are evident between the two sites, as the Lost Creek location is influenced by multiple golf courses and more dense single-family residential subdivisions.

Results from the Barton Creek datasondes are used in this report to assess: diurnal variation within Barton Creek, monthly variation, seasonality, differences between sites, relative affects of individual storm events, correlations between physical parameters and flow, correlations between physical parameters and antecedent rainfall, temporal changes and comparison to Texas Commission on Environmental Quality (TCEQ) water quality standards. Additionally, the quality of the datasonde data is evaluated by comparison of datasonde results to concurrent grab samples by COA personnel and correlation of number of days out with relative percent change in daily mean values.

Map 1. Datasonde deployment locations on Barton Creek.



Methods

All datasonde data is stored in the Hydstra, version 8.16.8, database. Data were extracted to delimited text files for use in SAS and manipulation (to associate with rainfall and flow) in Oracle.

Instantaneous flow measurements (at 5- or 15-minute intervals) from the United States Geological Survey (USGS) gage at Lost Creek (USGS 08155240) were obtained and associated to the corresponding datasonde measurement. Flow values were obtained for all but 2% of continuous monitoring measurements. Instantaneous rainfall measurements from the Flood Early Warning System (FEWS) gage at Fin Bridge (FEWS 2730) were summarized and associated to the datasonde data. Rainfall totals were summarized for 15-minute, 1-hour, 3-hour, 6-hour, 12-hour, 1-day, 2-day, 3-day, 4-day, 5-day, 7-day and 14-day periods prior to sample collection for comparison purposes. These simultaneous flow and rainfall data were correlated to continuous monitoring data to evaluate relationships between physical parameters and antecedent climatic conditions.

The distribution of each parameter was tested for normality using the Kolmogorov-Smirnov test; all parameters were normally distributed.

In multiple cases (9 events at Fin Bridge, 23 events at Lost Creek), field staff collected field measurements during the periods of datasonde deployment at or within 5 minutes apart under non-storm flow conditions over a range of datasonde deployment lengths (3-44 days out). These concurrent measurements are used to estimate the accuracy of datasonde measurements on long deployments as well as to correlate these estimates of error with deployment length, internal battery voltage and Lost Creek flow. Error was calculated as the datasonde value minus the field measurement value to estimate the absolute magnitude of difference between the concurrent measurements, and the percent coefficient of variation (the standard deviation expressed as a percentage of the mean) was used to determine the relative difference.

The Fin Bridge and Lost Creek sites were compared using both Spearman correlation analysis of simultaneous measurements and Duncan's multiple range test on mean values by month.

The relative percent difference in daily averages for each parameter and sampling day were calculated and compared to number of days out in an attempt to determine when datasonde sensors fail. Relative percent difference in daily averages was calculated between any two days according to the formula:

$$\mathrm{RPD} = [(X_{\mathrm{day1}} - X_{\mathrm{day2}}) / ((X_{\mathrm{day1}} - X_{\mathrm{day2}})/2)]*100$$

Datasonde data was screened individually by deployment to remove invalid data at the beginning or ending of any given deployment. However, invalid data (from sensor drift, debris clogging, etc.) most likely exists within each deployment. This data was not removed from analysis as identification of outliers would require an exorbitant amount of time, and the large number of measurements for each parameter (> 100,000) is expected to smooth outlier effects.

Comparison testing was performed by ANOVA (through the SAS generalized linear model procedure) and by Duncan's multiple range test. Correlation analyses were performed using both Spearman and Pearson correlation tests. Temporal trend analysis was also performed using the SAS generalized linear model procedure on daily averages grouped by season (summer, transitional and winter as described below) as well as the entire dataset. Annual averages were estimated and graphed to illustrate large-scale temporal patterns.

All statistical analyses were conducted using the SAS System, version 9.0, though additional graphing was performed using Microsoft Excel 2000.

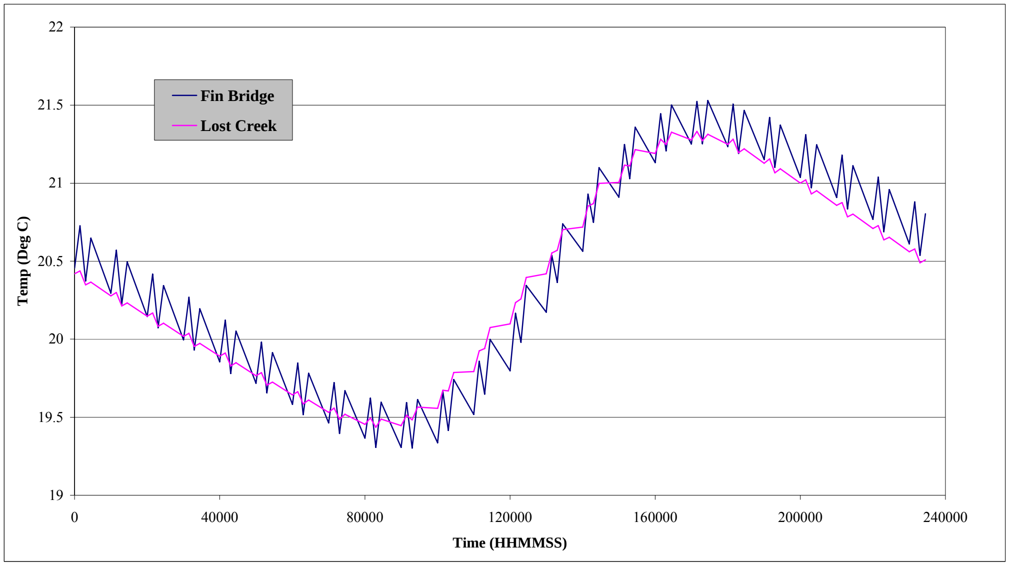
Results

Diurnal Variation

Daily fluctuations in parameters was assessed for both sites using all available data to describe the general diurnal patterns throughout the year.

Hourly average temperatures (Figure 1) indicate that Lost Creek (which maintains significantly cooler temperatures that Fin Bridge, see *Site Differences* below) cools more rapidly in the early evening hours, but generally follows expected patterns with maximum temperatures observed in the early evening (1800 hours) and minimum temperatures observed in the early morning (0800 hours).

Figure 1. Hourly average temperature (°C) by site.



Turbidity is not expected to follow a regular daily pattern, and the Lost Creek and Fin Bridge sites exhibit different hourly averages (Figure 2) most likely reflecting random differences resulting from inaccuracies of turbidity measurements. Although it is possible that storm flows could affect the sites in varying manners, the lack of similarly timed patterns in conductivity (Figure 3) make this an unlikely hypothesis. The clear difference in average conductivity values between the Fin Bridge and Lost Creek sites are evident. Though slight in magnitude, diurnal conductivity follows nearly identical, though reversed, patterns as temperature with maximums observed in the early morning and minimums observed in the early evenings.

Figure 2. Hourly average turbidity (NTU) by site.

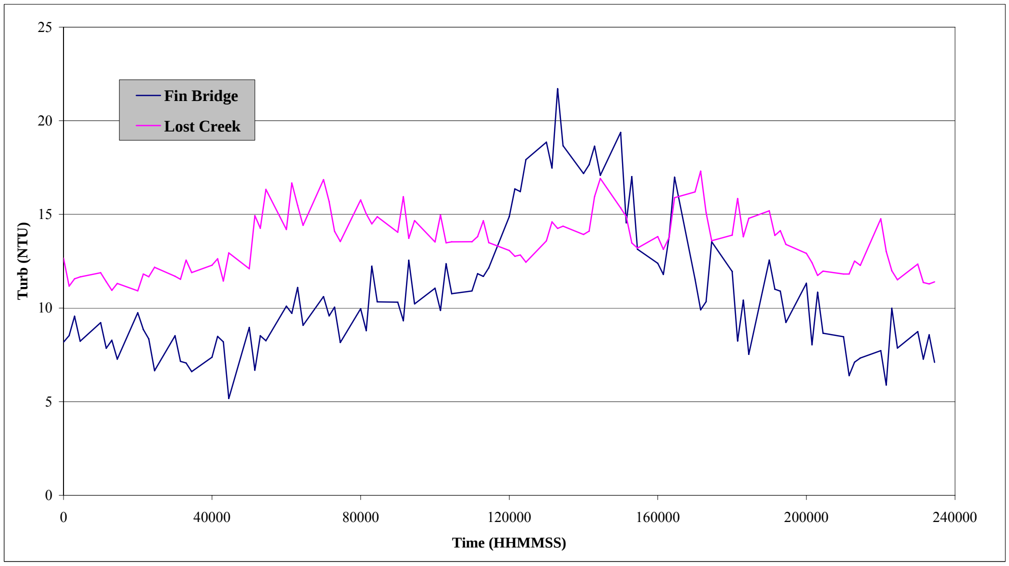
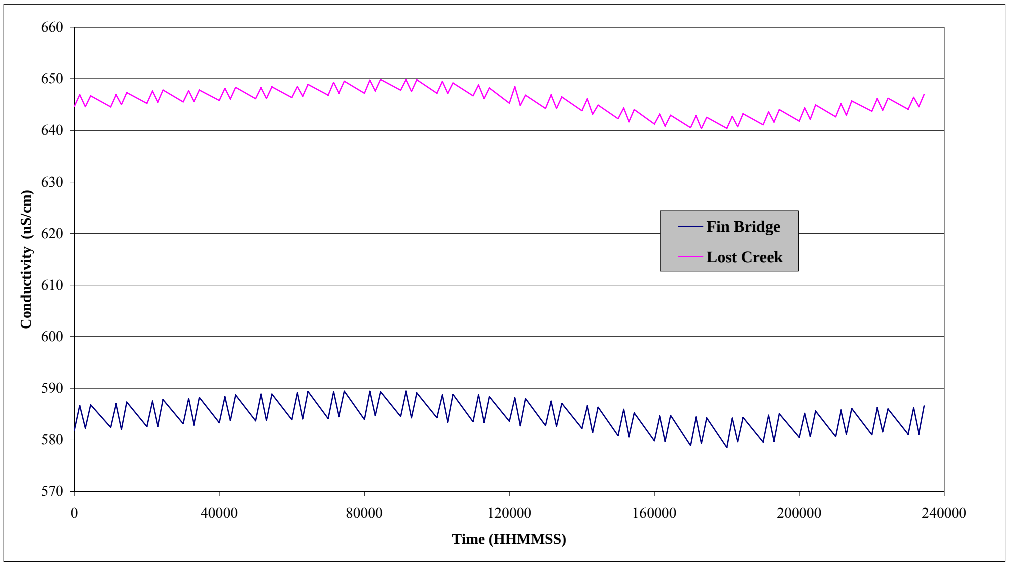


Figure 3. Hourly average conductivity (µS/cm) by site.



Diurnal pH patterns generally mimic temperature (Figure 4), though the actual amount of variation is extremely small (0.1 units). Note the more neutral pH measurements observed at the Lost Creek site relative to Fin Bridge. DO daily patterns also follow temperature as expected (Figure 5), though again Fin Bridge clearly maintains lower average DO values that Lost Creek.

Figure 4. Hourly average pH measurements by site.

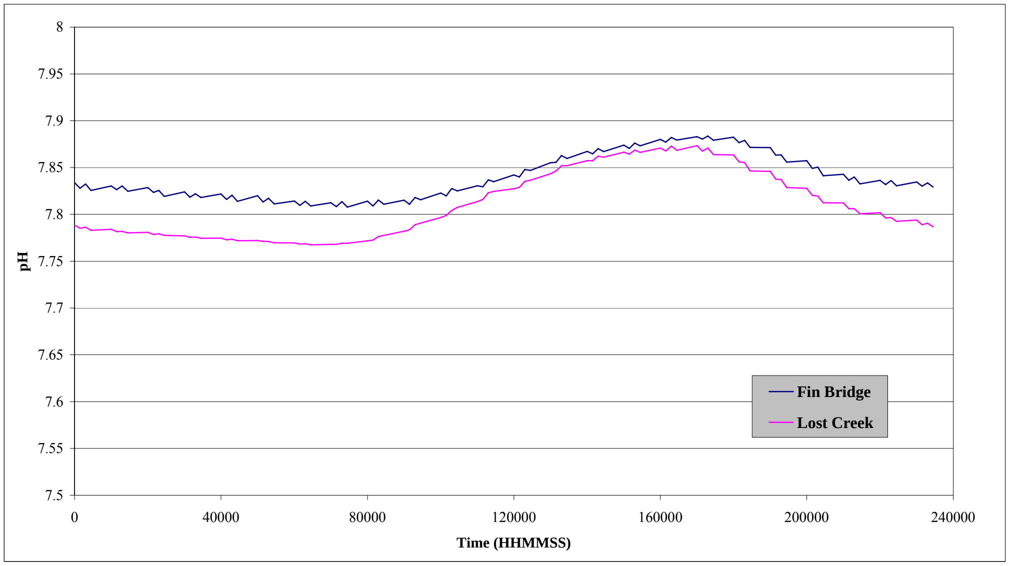
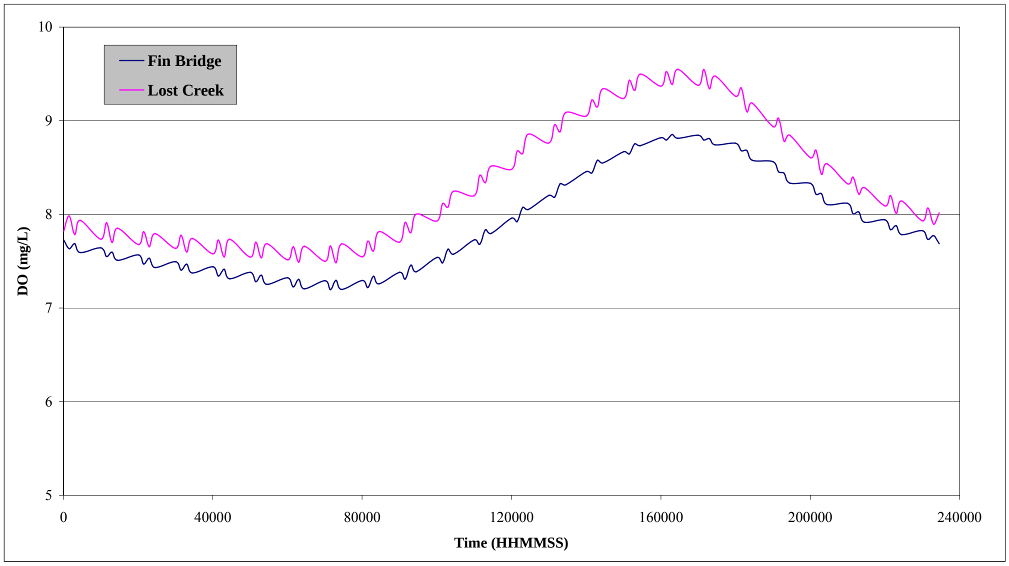


Figure 5. Hourly average DO (mg/L) by site.



Monthly Variation

Monthly mean values were calculated to represent the fluctuations over a yearly period. As expected, monthly mean temperatures strongly follow seasonally normal fluctuations in ambient air temperature in Austin with maximum monthly temperature values observed in July and August and minimum monthly temperature values observed in December and January (Figure 6). Monthly turbidity patterns (Figure 7) do not correspond to typical rainfall patterns based on the 30-year normal from 1971 to 2000, which predict maximum rainfall totals in May and October. Monthly turbidity patterns also are not significantly correlated with Lost Creek mean monthly flow values, although maximum average monthly flows are observed in July and November when turbidity values peak at the Lost Creek site.

Figure 6. Monthly mean temperature (°C) by site.

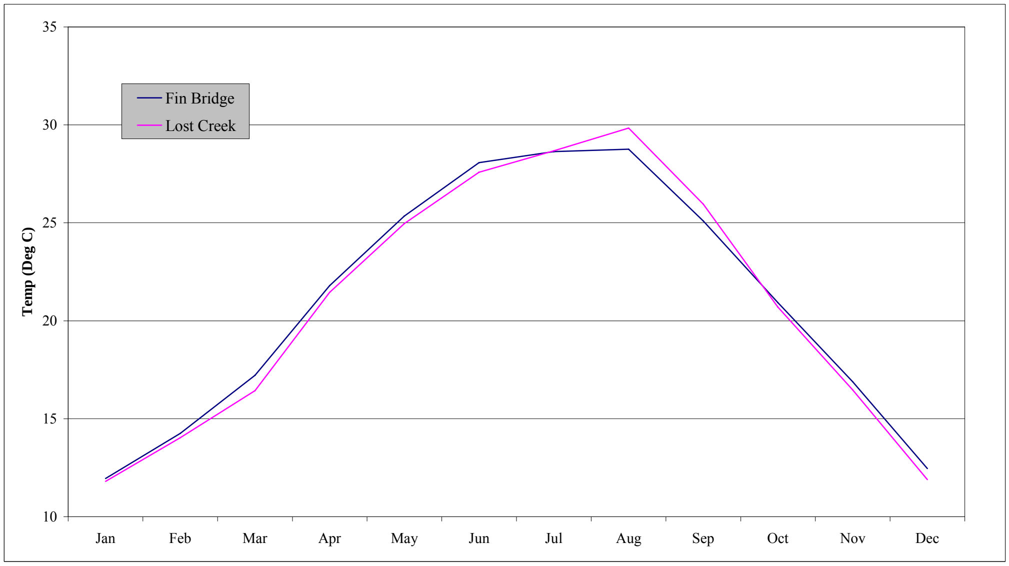
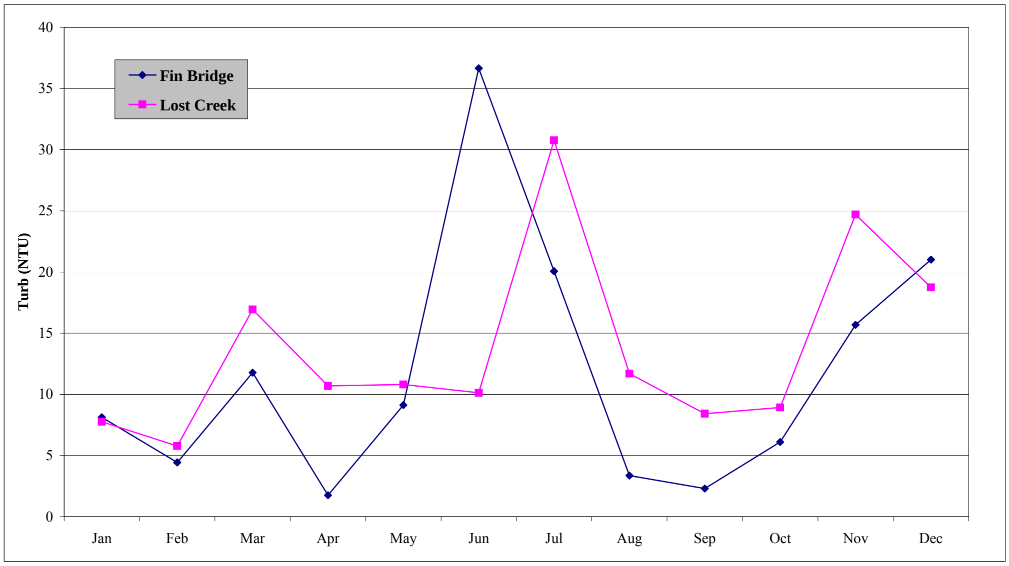
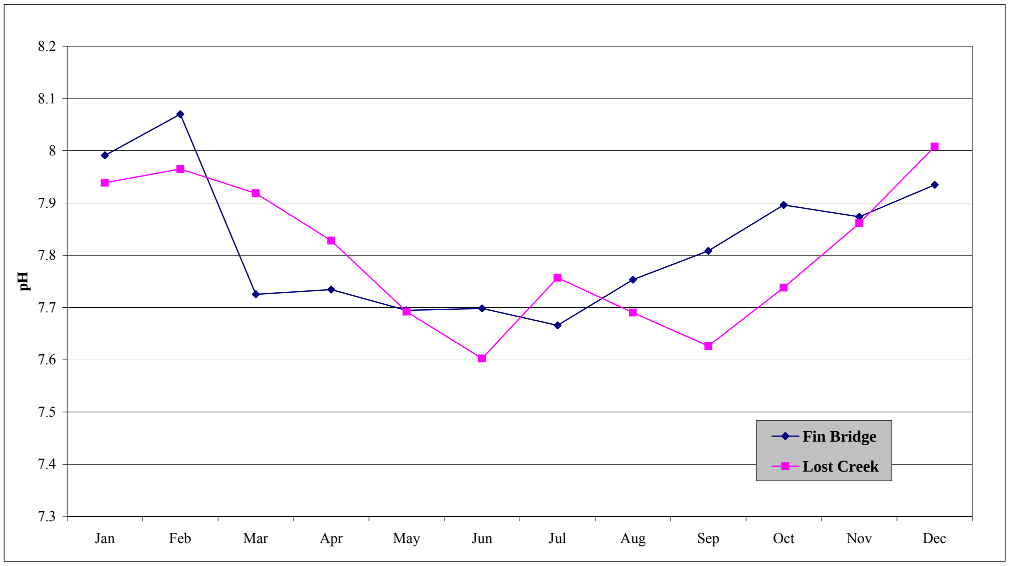


Figure 7. Monthly average turbidity (NTU) by site.



Monthly pH averages at both sites run generally opposite of observed monthly temperature patterns (Figure 8), with summer months exhibiting more neutral pH measurements. However, the total range of variation is numerically small and ranges less than 0.5 units.

Figure 8. Monthly average pH measurements by site.



Differences between sites are clearly evident in monthly average conductivity (Figure 9). Both sites yield different patterns in mean monthly conductivity, with Fin Bridge yielding maximum monthly averages in November through January, while Lost Creek yields maximum monthly average values in August and September. Both sites, however, yield low monthly average values in mid-summer months (June, July).

Because the solubility of oxygen is inversely related to water temperature, monthly mean DO yields the opposite pattern of temperature with minimum monthly average DO values observed in the hottest part of the summer as expected (Figure 10).

Figure 9. Monthly average conductivity (µS/cm) by site.

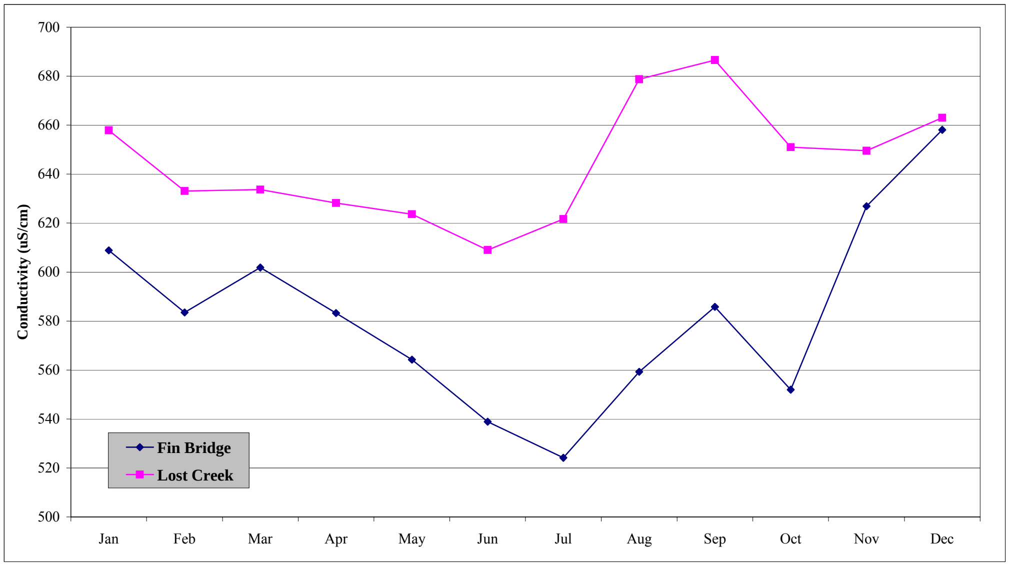
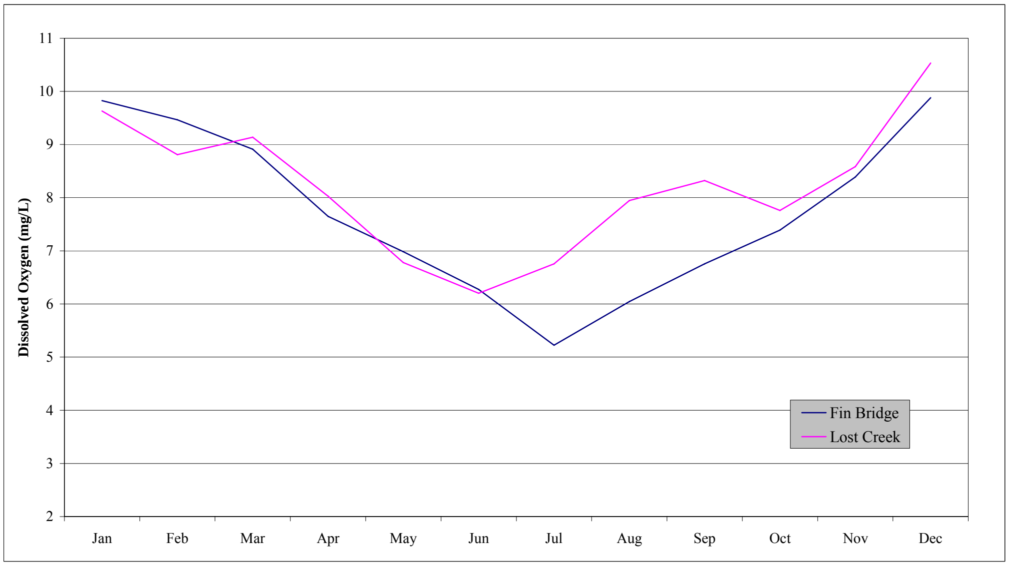


Figure 10. Monthly average DO (mg/L) by site.



Additionally, Duncan's multiple range test was used to compare monthly mean values by site for each parameter (Table 1). Monthly means for each parameter at each site with the same Duncan grouping are not significantly different from one another.

Table 1. Duncan's multiple range test on monthly means for each parameter by site. Note that monthly means with the same Duncan grouping letter for a given site and parameter are not significantly different from one another.

	Fin Bridge			**Lost Creek**		
Param	**Duncan Group**	**Mean**	**Month**	**Duncan Group**	**Mean**	**Month**
Temperature, Deg C	A	28.76	8	A	29.84	8
	B	28.63	7	B	28.68	7
	C	28.08	6	C	27.58	6
	D	25.34	5	D	25.95	9
	E	25.09	9	E	24.97	5
	F	21.79	4	F	21.45	4
	G	20.93	10	G	20.70	10
	H	17.22	3	H	16.48	11
	I	16.89	11	H	16.44	3
	J	14.25	2	I	14.03	2
	K	12.46	12	J	11.89	12
	L	11.95	1	K	11.80	1
Turbidity, NTU	A	36.66	6	A	30.76	7
	B	21.02	12	B	24.70	11
	B	20.07	7	C	18.74	12
	C	15.68	11	D	16.94	3
	D	11.77	3	E	11.69	8
	E	9.11	5	F, E	10.80	5
	E	8.13	1	F, E	10.69	4
	F	6.11	10	F, G	10.13	6
	G, F	4.43	2	H, G	8.92	10
	G, H	3.36	8	H, G	8.42	9
	H	2.30	9	H, G	7.77	1
	H	1.75	4	I	5.77	2
pH	A	8.07	2	A	8.01	12
	B	7.99	1	B	7.96	2
	C	7.93	12	C	7.94	1
	D	7.90	10	D	7.92	3
	E	7.87	11	E	7.86	11
	F	7.81	9	F	7.83	4
	G	7.75	8	G	7.76	7
	H	7.73	4	H	7.74	10
	I	7.73	3	I	7.69	5
	J	7.70	6	I	7.69	8
	J	7.69	5	J	7.63	9
	K	7.67	7	K	7.60	6
Conductivity, uS/cm	A	658.12	12	A	686.61	9
	B	626.94	11	B	678.74	8
	C	608.90	1	C	663.04	12
	D	601.84	3	D	657.89	1
	E	585.81	9	E	651.01	10
	E	583.48	2	E	649.57	11
	E	583.23	4	F	633.71	3
	F	564.20	5	F	633.10	2
	G	559.24	8	G	628.23	4
	H	552.01	10	H	623.64	5
	I	538.87	6	H	621.64	7
	J	524.17	7	I	609.02	6
Dissolved Oxygen, mg/L	A	9.88	12	A	10.53	12
	B	9.83	1	B	9.63	1
	C	9.46	2	C	9.14	3
	D	8.91	3	D	8.81	2
	E	8.39	11	E	8.58	11

	F	7.65	4	F	8.32	9
	G	7.39	10	G	8.03	4
	H	6.99	5	H	7.95	8
	I	6.75	9	I	7.76	10
	J	6.27	6	J	6.78	5
	K	6.05	8	J	6.76	7
	L	5.23	7	K	6.20	6
Depth, Feet	A	2.70	12	A	2.78	12
	A	2.69	11	B	2.51	11
	B	2.54	3	C	2.44	1
	C	2.43	1	D	2.40	2
	D	2.37	2	E	2.38	3
	E	2.33	4	F	2.24	7
	F	2.11	10	F	2.24	4
	G	2.09	5	G	2.04	5
	H	1.91	7	H	1.98	6
	I	1.83	8	H	1.97	10
	J	1.81	9	I	1.36	8
	J	1.79	6	J	1.30	9

Seasonality

Analysis of monthly temperature variation was used in an attempt to define seasonality within the waters of Barton Creek. Observations of field staff have previously noted a lack of four well-defined equal-length seasons in Central Texas streams based on stream hydrology in combination with climatic factors (rainfall, ambient air temperature, etc). Monthly average temperatures at both sites (Figure 11 and 12) support a two-season grouping (summer, winter) with a single-month transitional period between the two extremes. Winter months run from November to March, characterized by temperatures near 15ºC (59ºF), and summer months run from May to September, characterized by temperatures between 25 (77ºF)and 30ºC (86ºF). April and October are the transitional months when temperatures are approximately 20ºC (68ºF). The two-season pattern is evident and statistically significant at both sites, though the groupings are most defined at Lost Creek.

Figure 11. Hourly average temperature by month at Lost Creek.

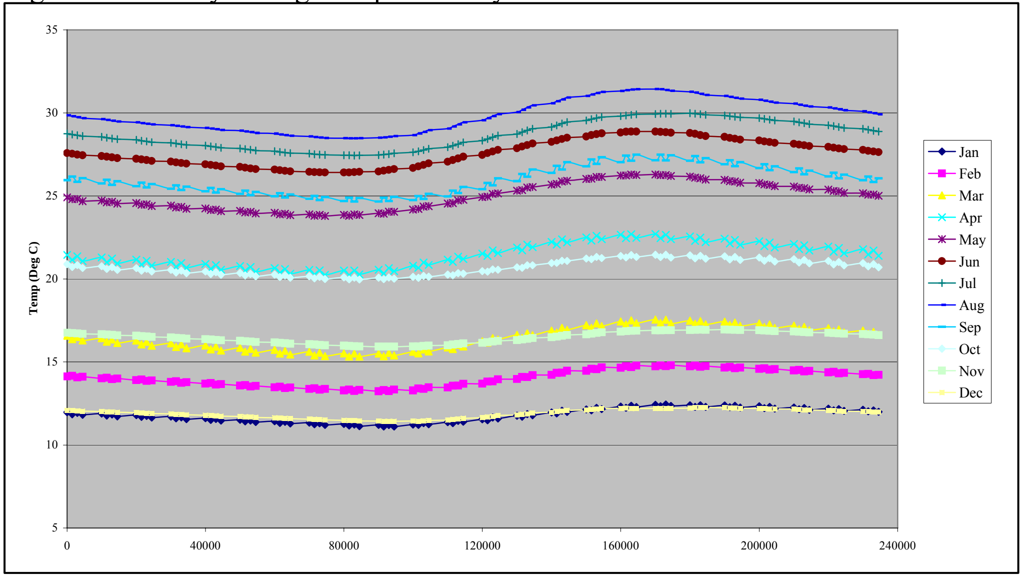
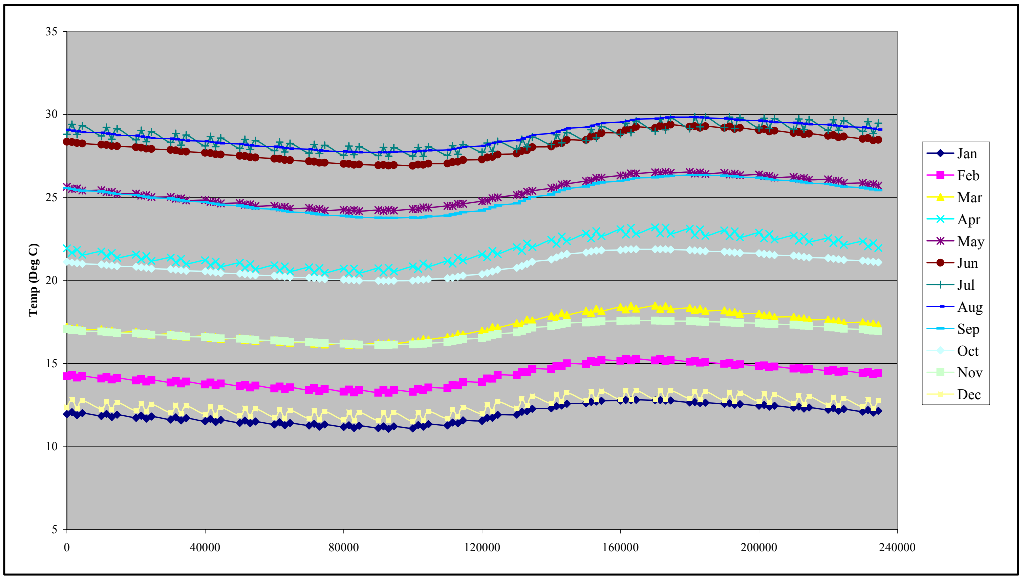


Figure 12. Hourly average temperature by month at Fin Bridge.



Daily patterns generally remain the same regardless of month, though as is expected variation between minimum and maximum temperatures is greater in the summer months.

The statistically significant seasonal groupings derived from water temperature were applied to the other physical parameters, and means were tested using Duncan's multiple range test (Table 2). Relationships between summer and winter means followed similar patterns for all parameters except conductivity, which exhibited significantly higher mean values in the winter at Fin Bridge but significantly higher mean values in the summer at Lost Creek. One potential explanation for this phenomenon is the addition of higher conductivity water during summer months at the Lost Creek site from golf course effluent irrigation or discharge of high conductivity springs potentially recharged by leaking effluent holding ponds. The relative position of the transitional months could also be an artifact of sample size, as only 20% of data points fell within this season in comparison to approximately 40% of the total data set in both winter and summer months.

Table 2. Comparison of seasonal means by parameter (Winter = Nov-Mar, Trans=Apr, Oct, Summer=May-Sep). Significantly different means ($p<0.05$) separated by ">" in order of magnitude.

Parameter	**Fin Bridge**	**Lost Creek**
Temperature	Summer > Trans > Winter	Summer > Trans > Winter
Turbidity	Winter, Summer > Trans	Winter > Summer > Trans
pH	Winter > Summer > Trans	Winter > Trans > Summer
Conductivity	Winter > Trans > Summer	Summer > Winter > Trans
DO	Winter > Trans > Summer	Winter > Summer > Trans
Depth	Winter > Trans > Summer	Winter > Trans > Summer

Site Comparison

Duncan's multiple range test on monthly mean values between the two sites detail the basic differences in physical parameters between the Lost Creek and Fin Bridge locations (Table 3). Fin Bridge maintains warmer temperatures than Lost Creek for all months of the year except the hottest months (July through September). Lost Creek maintains higher conductivity values all year long, highlighting potential impacts of the golf courses and development between the two monitoring sites. Several springs, potentially recharged by a golf course holding pond, discharge high nutrient and conductivity waters immediately upstream of the Lost Creek site and could also be a source of the elevated conductivity. Turbidity values are also generally higher at Lost Creek, further implicating Lost Creek as the more development-impacted site. DO and pH fluctuate, though Lost Creek generally maintains higher DO values and more acidic pH values than Fin Bridge. However, both the frequency of neutral pH values (near 7) and the total range of pH values is higher at Fin Bridge relative to Lost Creek. Depth at Fin Bridge appears higher than Lost Creek in the spring and fall calendar months.

Table 3. Statistically significant differences ($p<0.05$) between monthly means at the Lost Creek (LC) and Fin Bridge (FB) sites. No statistical difference (nd) noted. Arrows indicate direction of difference.

Month	Temp	DO	pH	Conductivity	Depth	Turbidity
Jan	FB > LC	FB > LC	FB > LC	LC > FB	nd	nd
Feb	FB > LC	FB > LC	FB > LC	LC > FB	LC > FB	LC > FB
Mar	FB > LC	LC > FB	LC > FB	LC > FB	FB > LC	LC > FB
Apr	FB > LC	LC > FB	LC > FB	LC > FB	FB > LC	LC > FB
May	FB > LC	FB > LC	nd	LC > FB	FB > LC	LC > FB
Jun	FB > LC	FB > LC	FB > LC	LC > FB	LC > FB	FB > LC
Jul	nd	LC > FB	LC > FB	LC > FB	LC > FB	LC > FB
Aug	LC > FB	LC > FB	FB > LC	LC > FB	FB > LC	LC > FB
Sep	LC > FB	LC > FB	FB > LC	LC > FB	FB > LC	LC > FB
Oct	FB > LC	LC > FB	FB > LC	LC > FB	FB > LC	LC > FB
Nov	FB > LC	LC > FB	FB > LC	LC > FB	FB > LC	LC > FB
Dec	FB > LC	LC > FB	LC > FB	LC > FB	LC > FB	FB > LC

Spearman correlation analysis between sites using simultaneous measurements yields strong correlation between temperature (Figure 13), conductivity and depth (Table 4). Reasonably high correlation between sites is observed for pH (Figure 14) and DO (Figure 15). The higher DO values at Lost Creek relative to Fin Bridge are evident in the comparison plot, as is the higher total variance in pH at Fin Bridge relative to Lost Creek.

Figure 13. Lost Creek versus Fin Bridge simultaneous temperature measurements.

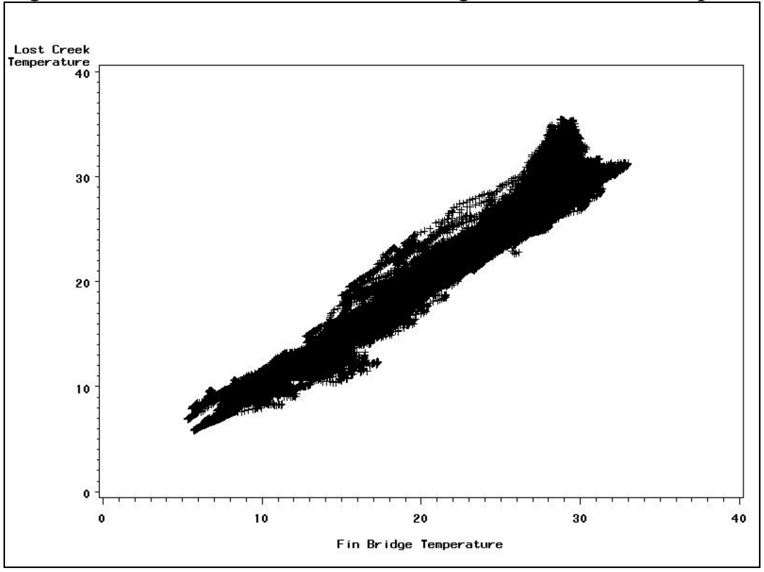


Table 4. Spearman correlation analysis between Fin Bridge and Lost Creek sites ($p<0.0001$ for all parameters).

	Temp	**Turb**	**pH**	**Cond**	**DO**	**Depth**
θ	0.99	-0.06	0.53	0.76	0.58	0.88
n	126,364	105,212	114,394	121,024	117,196	125,668

Figure 14. Lost Creek versus Fin Bridge simultaneous pH measurements.

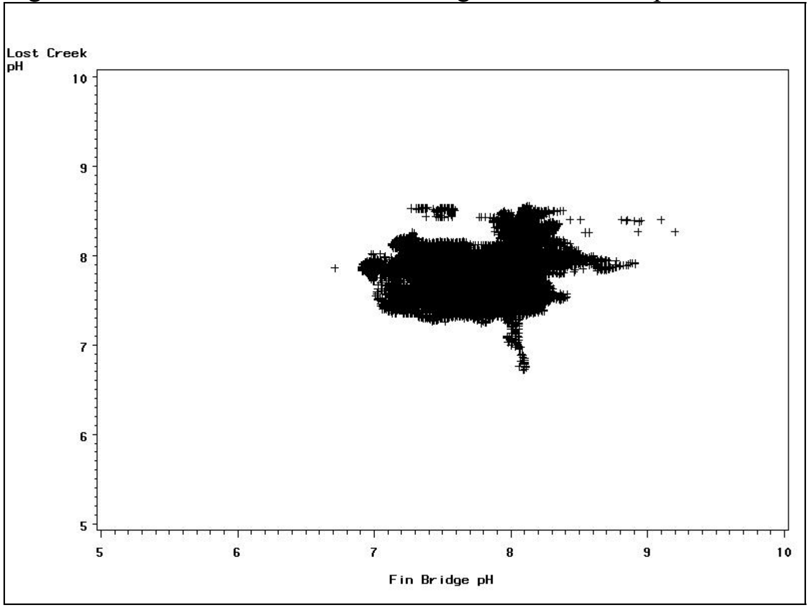
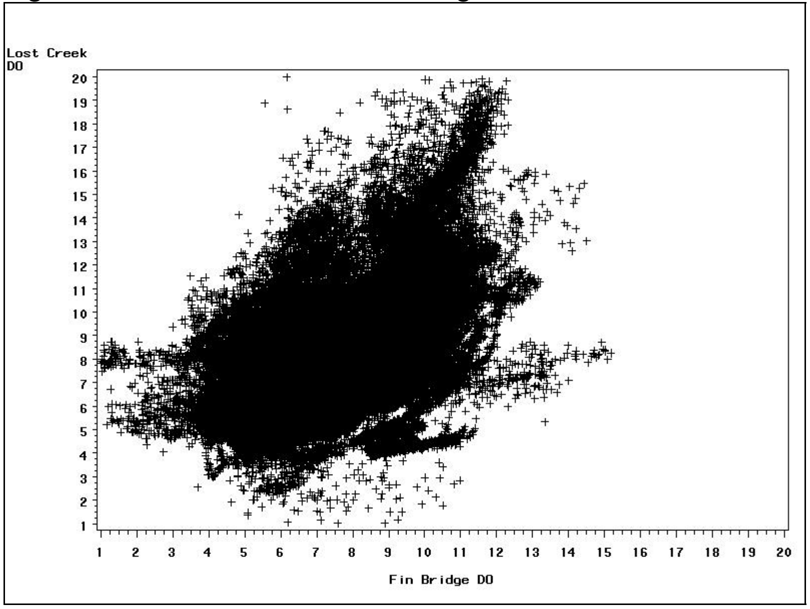
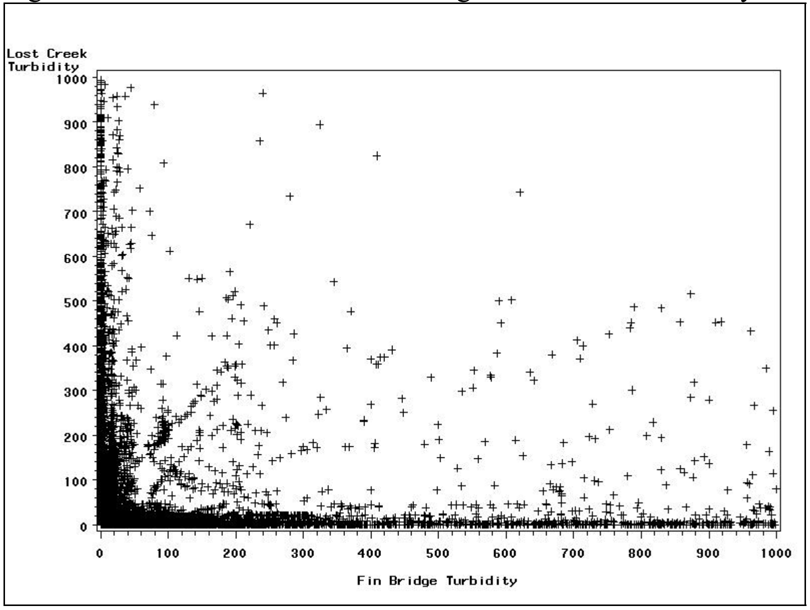


Figure 15. Lost Creek versus Fin Bridge simultaneous DO measurements.



Though statistically significant (influenced by the extremely large number of measurements), correlation between sites for turbidity is poor, and highlights the extreme variability in turbidity measurements at both sites (Figure 16).

Figure 16. Lost Creek versus Fin Bridge simultaneous turbidity measurements.

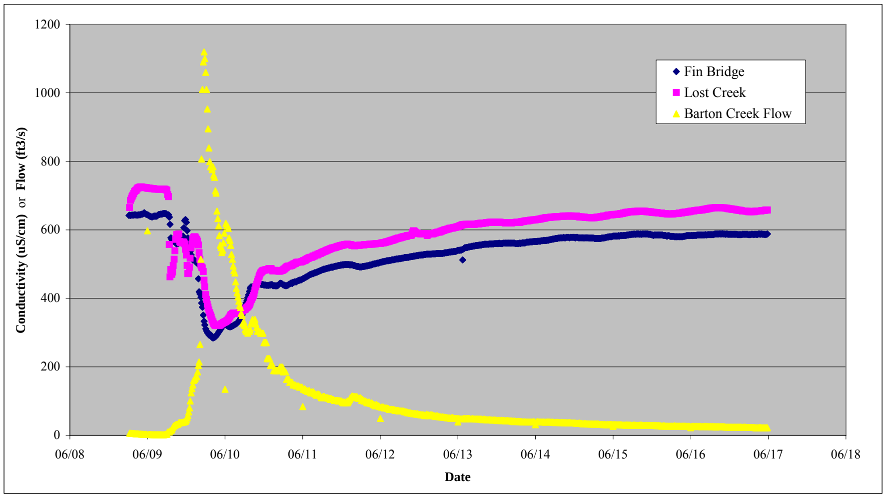


Individual Event Effects

Analysis of individual storm events clearly demonstrate the response of each parameter to run-off. As expected, conductivity decreases following storm events while pH and turbidity increase. Despite an expected decrease in DO following storm events as an oxygen demand is exerted by the organic matter delivered to the creek with storm runoff, DO appears generally unaffected by storm flow. Response of temperature to rainfall events depends on time of year, but generally decreases with rainfall.

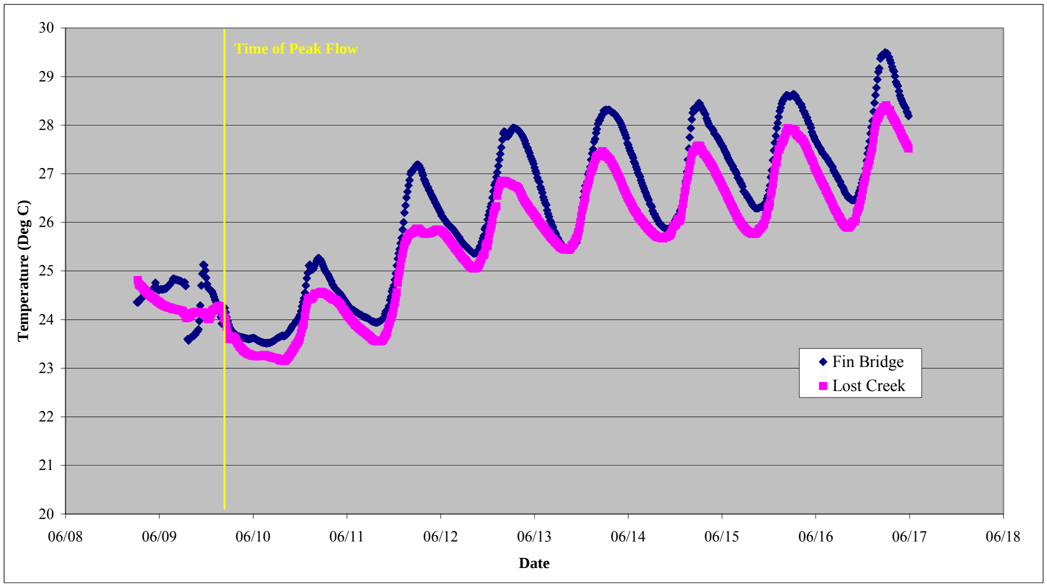
A median size summer storm event (maximum instantaneous flow ≈ 1,100 ft^3/s) occurred in June 2000, when Barton Creek flows peaked in the evening of 9 June 2000, following 2.3 inches of rain in approximately 12 hours. Conductivity sharply decreases with increasing runoff (Figure 17), and does not approach stable, pre-storm monthly average levels until approximately 4 days after the event. Lost Creek again clearly maintains higher conductivity levels than Fin Bridge.

Figure 17. Conductivity at Lost Creek and Fin Bridge with Barton Creek flows following a storm event of 2.3 inches on June 9, 2000.



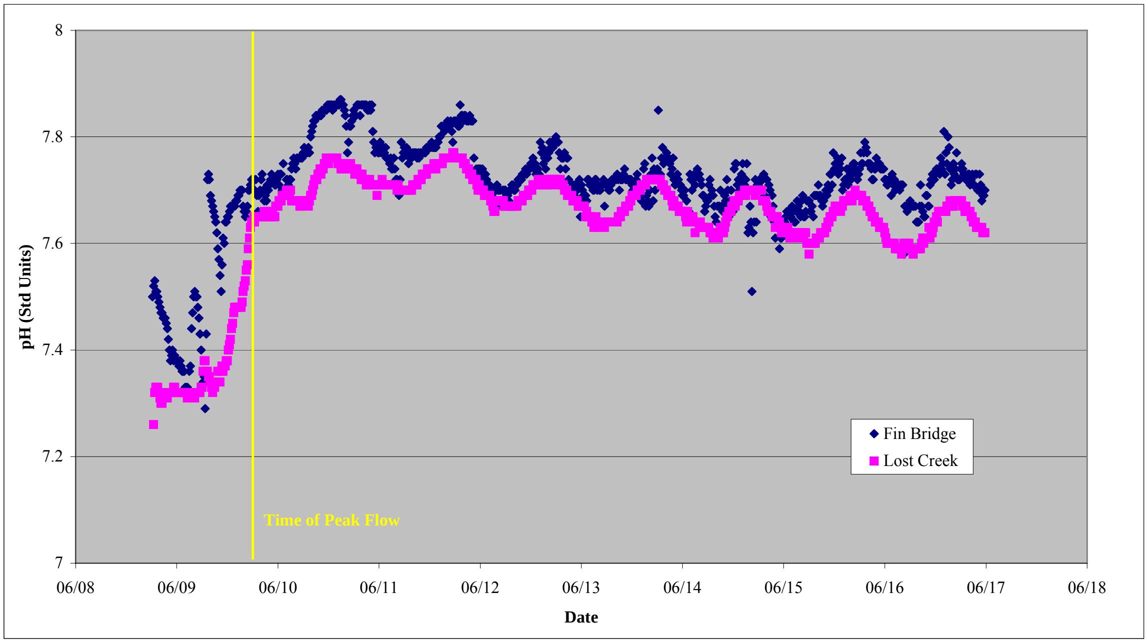
Temperature decreases immediately following the storm event (Figure 18), but daily oscillations are resumed in the afternoon of the day following the storm event and continue to increase in magnitude until seasonally normal monthly average temperature values of 28ºC levels are reached approximately 5 days after the event. Fin Bridge again clearly maintains higher maximum temperature values than Lost Creek.

Figure 18. Temperature at Lost Creek and Fin Bridge following a storm event of 2.3 inches on June 9, 2000. The yellow indicates time of peak Barton Creek flow.



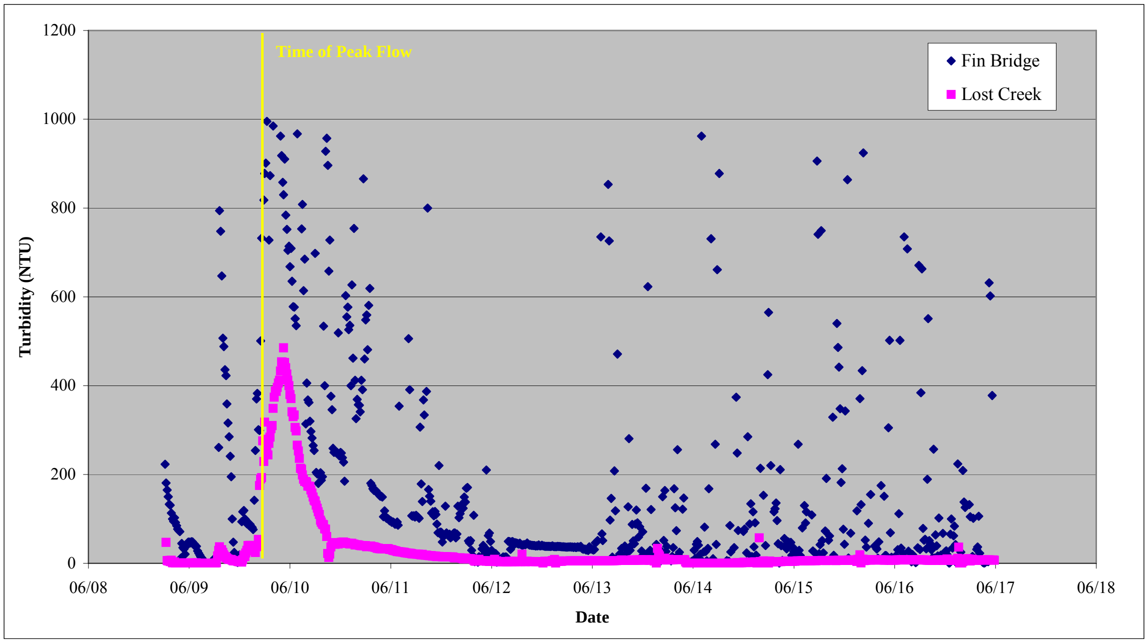
During the actual runoff event, pH values rapidly increase, stabilize in approximately one day following the event, and then decrease slowly while following patterns of daily fluctuations (Figure 19). pH values do not return to the June monthly average value of 7.6 until approximately 5 days after the peak flow value. Fin Bridge again consistently maintains more basic pH values than Lost Creek. The increased variability in pH measurements at Fin Bridge could be the result of instrumentation error, or could reflect the presence of a more neutral source water at Lost Creek overwhelming natural variability driving Lost Creek pH to a more consistent level.

Figure 19. pH at Lost Creek and Fin Bridge following a storm event of 2.3 inches on June 9, 2000. The yellow indicates time of peak Barton Creek flow.



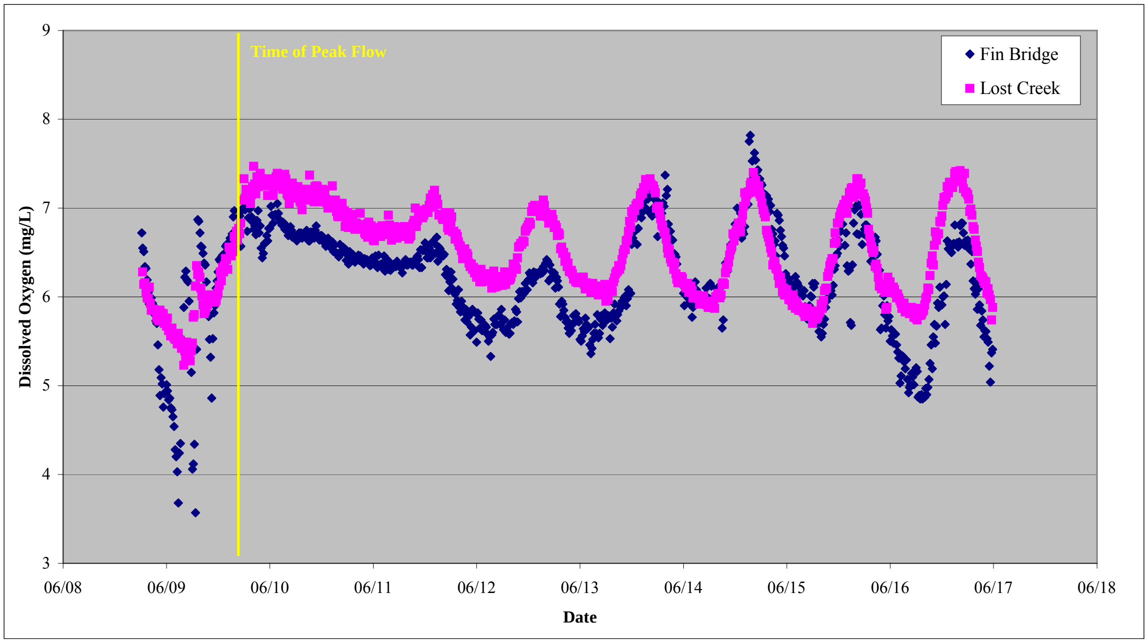
Problems in turbidity instrumentation at the Fin Bridge site are clearly evident when examined for the June 9, 2000, storm event (Figure 20). The effects of storm flow on turbidity are present at both sites, though the wide fluctuations at Fin Bridge, especially after turbidity values at Lost Creek have returned to pre-storm values, further illustrate error in turbidity measurement by datasonde instruments. Turbidity at Lost Creek returns to pre-storm average values more rapidly than several other parameters, with recovery time lasting approximately 3 days. Though it is possible that turbidity may be more variable during storm events at Fin Bridge, it is unlikely as Fin Bridge is the less-developed site and as the high turbidity values in the weeks following the storm do not correspond with the more reasonable Lost Creek measurements.

Figure 20. Turbidity at Lost Creek and Fin Bridge following a storm event of 2.3 inches on June 9, 2000. The yellow indicates time of peak Barton Creek flow.



DO would be expected to increase during the immediate storm event simply due to increased agitation from turbulent water flow, then decrease as organic matter decomposition exerts an oxygen demand once the storm event has subsided. Following the summer storm of June 9, 2000, however, DO appears relatively unaffected by storm runoff (Figure 21). DO values increase during the storm, then following the peak flow begin to decrease but never experience a large dip as routine daily fluctuations return in only 2 days after the storm event. Again, Lost Creek maintains higher DO values than Fin Bridge. Similar to pH and turbidity, DO at Fin Bridge is more variable on a daily basis than Lost Creek though it is unknown if the increased variation is the result of instrumentation error or natural site-related variability.

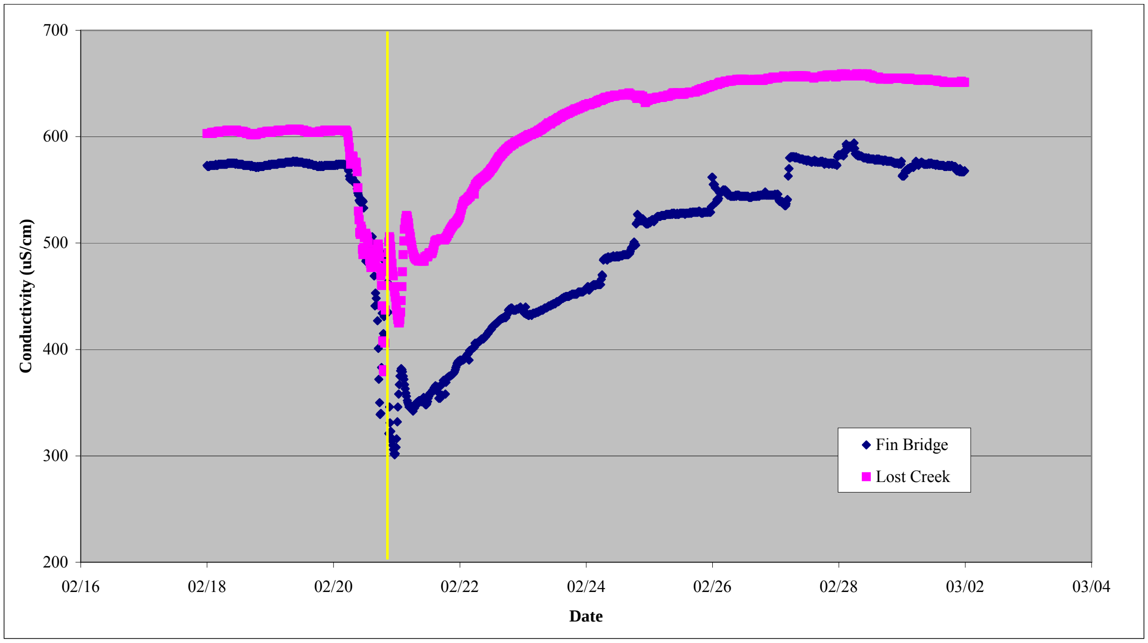
Figure 21. DO at Lost Creek and Fin Bridge following a storm event of 2.3 inches on June 9, 2000. The yellow indicates time of peak Barton Creek flow.



A winter storm of peak magnitude (maximum instantaneous flow ≈ 1,700 ft^3/s) similar to the 9 June 2000 storm occurred in Barton Creek on the evening of 20 February 2003, following 1.45 inches of rain in the preceding 17 hours. This storm was analyzed to determine if differences between summer and winter storms could be visually determined by graphical analyses.

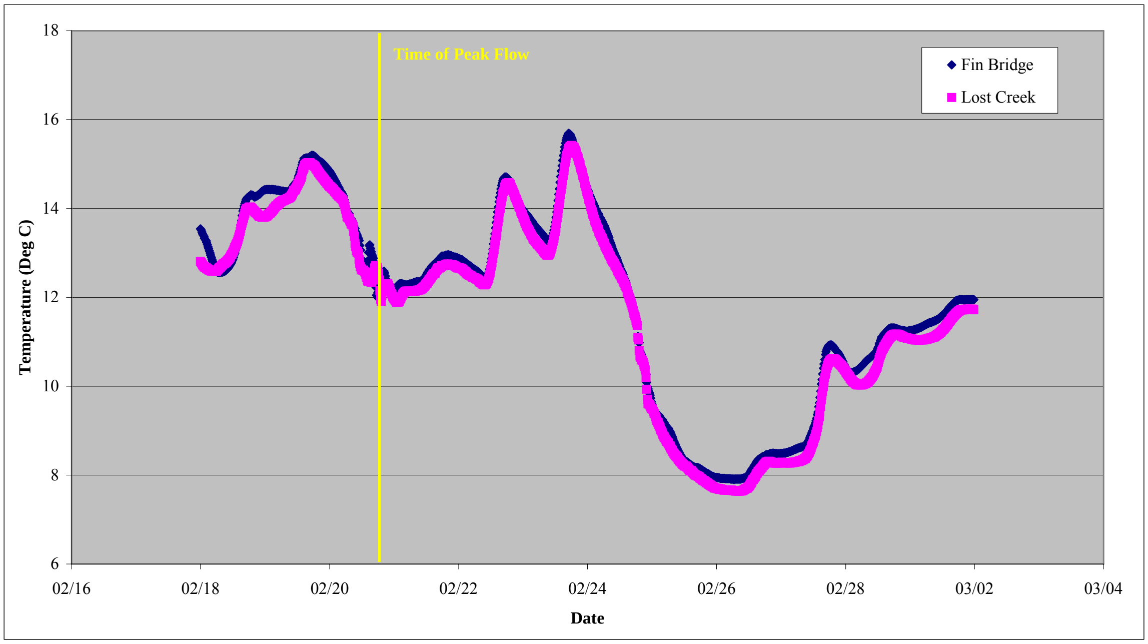
Again, conductivity rapidly decreases during the storm event, then gradually returns to pre-storm levels (Figure 22). Recovery to pre-storm conductivity levels following the winter storm is much more rapid at Lost Creek (2 days) than Fin Bridge (5 days), suggesting the input of additional higher conductivity water potentially from groundwater sources.

Figure 22. Conductivity at Lost Creek and Fin Bridge following a storm event of 1.45 inches on February 20, 2003. The yellow indicates time of peak Barton Creek flow.



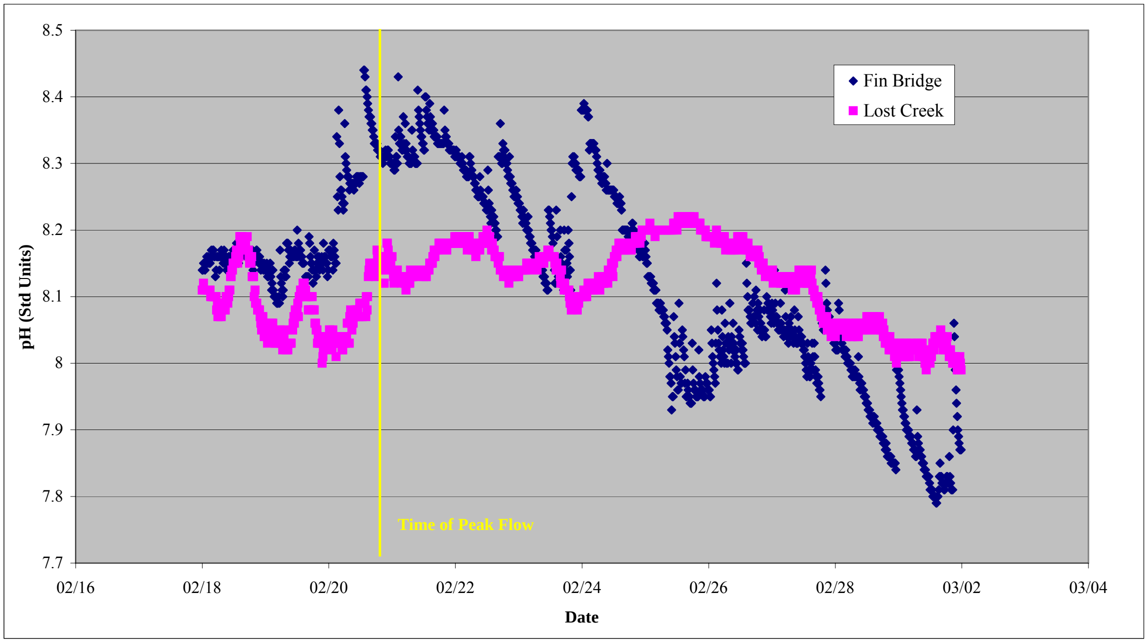
Water temperature following the winter storm event mimics the storm response in the summer as temperature falls during the peak of the storm, then increases until a cold front arrives in Austin on 24 February, driving ambient air temperatures from 15ºC (59ºF) to 1ºC (33ºF), providing a unique opportunity to highlight the affect of ambient air temperature on Barton Creek water temperature (Figure 23).

Figure 23. Temperature at Lost Creek and Fin Bridge following a storm event of 1.45 inches on February 20, 2003. The yellow indicates time of peak Barton Creek flow.



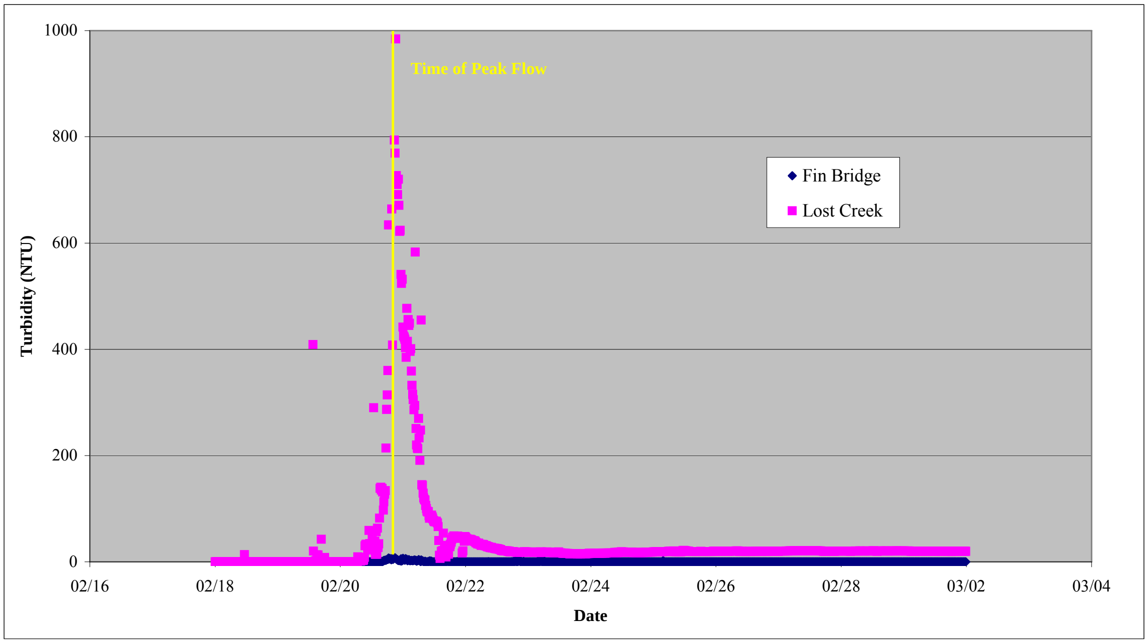
Following the February 2003 storm event, pH increases at the time of peak flow, then seems to fluctuate wildly with no diurnal pattern evident for more than a week following the storm event, especially at Fin Bridge (Figure24).

Figure 24. pH at Lost Creek and Fin Bridge following a storm event of 1.45 inches on February 20, 2003. The yellow indicates time of peak Barton Creek flow.



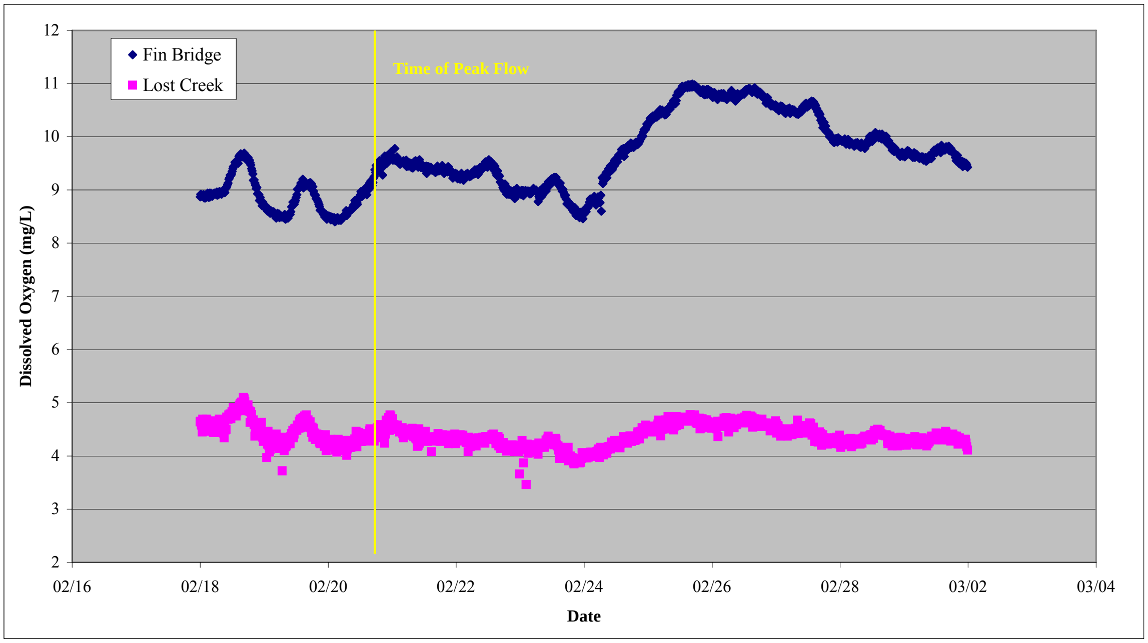
Response of turbidity following the winter storm examined is as expected, although the maximum turbidity observed at Fin Bridge is only 9.7 NTU versus a maximum of 984 NTU at Lost Creek (Figure 25). Though Lost Creek would be expected to yield a higher peak storm flow turbidity value than Fin Bridge under nominal conditions, the extremely large difference between values at the two sites is most likely due to instrumentation problems.

Figure 25. Turbidity at Lost Creek and Fin Bridge following a storm event of 1.45 inches on February 20, 2003. The yellow indicates time of peak Barton Creek flow.



Again, DO remains relatively unaffected by the storm event. The cold front arriving on 24 February does more to change the DO value than the storm event (Figure 26).

Figure 26. DO at Lost Creek and Fin Bridge following a storm event of 1.45 inches on February 20, 2003. The yellow indicates time of peak Barton Creek flow.



The lack of DO changes following storm events was examined for the largest storm captured during a datasonde deployment on Barton Creek. On the evening of 2 July 2002, peak flow at Lost Creek reached 26,100 ft^3/s following 2.54 inches of rain in the preceding 36 hours. Again no substantial changes in DO concentration following the storm event were observed. A small storm event on the morning of 11 December 1998 in which Barton Creek flows peaked at 123 ft^3/s following 0.91 inches of rain in the preceding 32 hours also yielded no substantial changes in DO.

Correlation with Flow

Spearman correlation analysis by site with instantaneous Lost Creek flow measurements yield statistically significant relationships with all parameters except turbidity (at Fin Bridge only) at both sites (Table 5). Depth yields the strongest relationships with flow at both sites.

Table 5. Correlation analysis with flow.

	Temperature	**Turbidity**	**pH**	**Conductivity**	**DO**	**Depth**
Lost Creek						
θ	-0.42	0.25	0.66	-0.60	0.27	0.86
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
n	143,451	138805	143,451	143,451	140,134	143,451
Fin Bridge						
θ	-0.42	0.01	0.30	-0.20	0.40	0.78
p	<0.0001	0.08	<0.0001	<0.0001	<0.0001	<0.0001
n	129,020	111,671	117,048	123,613	123,139	128,324

Temperature is negatively related to flow, corresponding to expected seasonal variation of higher flows in cooler months. This seasonal variation also could explain the positive correlation of DO with flow as colder waters have higher oxygen solubility. Conductivity also yields an inverse relationship with flow, particularly at the Lost Creek site, suggesting potential groundwater or wastewater effluent irrigation water influences that are diluted under high flow conditions. The positive relationship between pH and flow could also be explained by the groundwater as more neutral spring water is diluted by increased and more basic surface water flow. The average pH of Lost Creek Springs, located upstream of the Lost Creek datasonde deployment site, is 7.07 whereas the average pH of Barton Creek at Lost Creek is 7.8 based on all available instantaneous field measurement data.

The large difference in correlation coefficients for turbidity with flow at the Lost Creek site versus the Fin Bridge site are not immediately explainable. High variability and low accuracy in turbidity sensor readings could account for this discrepancy if the Fin Bridge instrument was more likely to foul or drift than the Lost Creek instrument.

Correlation with Rainfall

No parameter was strongly correlated with rainfall at any summation period from total rainfall in the previous 15 minutes to total rainfall in the previous 14 days (Table 6). The largest Spearman correlation coefficients ($\theta \approx 0.32$) at both sites were observed for depth versus total rainfall in the previous 14 days. Although the rainfall gage was located near the Fin Bridge site, fewer parameters were significantly correlated with rainfall summations at Fin Bridge in comparison to Lost Creek.

Table 6. Maximum Spearman correlation coefficients with rainfall summations by parameter and site.

Parameter	Fin Bridge	Lost Creek
Temperature	Rain in last 14 days ($\theta = -0.19$, $p<0.01$)	Rain in last 7 days ($\theta = -0.18$, $p<0.01$)
Turbidity	Rain in last 14 days ($\theta = 0.10$, $p<0.01$)	Rain in last 3 days ($\theta = 0.15$, $p<0.01$)
pH	Rain in last 5 days ($\theta = 0.07$, $p<0.01$)	Rain in last 5 days ($\theta = 0.14$, $p<0.01$)
Conductivity	Rain in last 2 days ($\theta = -0.11$, $p<0.01$)	Rain in last 3 days ($\theta = -0.17$, $p<0.01$)
DO	Rain in last 7 days ($\theta = 0.06$, $p<0.01$)	Rain in last 5 days ($\theta = 0.05$, $p<0.01$)
Depth	Rain in last 14 days ($\theta = 0.31$, $p<0.01$)	Rain in last 14 days ($\theta = 0.34$, $p<0.01$)

At both sites, temperature and conductivity were negatively related to rainfall, while turbidity, pH and depth were positively related to rainfall summations. DO was generally not correlated to rainfall summations at either site, with the maximum correlation coefficient for DO observed at Fin Bridge for total rainfall in the past 7 days ($\theta = 0.06$).

The absolute magnitude of correlation coefficients generally increased with increasing summation periods for temperature, turbidity, pH and depth at both sites. Conductivity at Fin Bridge yielded a unique effect in which correlation coefficients increased through the 2-day summation point, then decreased with increasing summation lengths. Although conductivity at the Lost Creek site yielded maximum correlation with rainfall in the 2-, 3- and 4-day summation periods ($\theta \approx 0.16$) , there was no substantial decrease with increasing summation period as observed at the Fin Bridge site ($\theta \approx 0.15$).

Although the results of this analysis were intended to potentially confirm or modify the current COA policy on the timing of non-storm influenced sample collection, the lack of strong correlations between any of the physical parameters assessed with antecedent rainfall (despite a variety of reasonable summation periods) do not provide any clear opportunities for modification of the policy at this time.

Temporal Trends

Temporal trends were examined for both daily and annual averages by parameter for each site, with additional temporal trend analysis conducted on data grouped by season (summer, transitional, winter). Note that data in 2004 ends in February, and does not represent a complete year.

As expected from the large number of data points covering such a diverse range of climatic conditions, no clear temporal trends were evident. Annual averages and daily averages yielded extreme values in 2000 for several parameters. Temperature (Figure 27), turbidity (Figure 28) and conductivity (Figure 31, below) yielded maximum annual averages in 2000, while pH (Figure 29) yielded the minimum annual average at both sites. Although 2000 yielded an annual average flow below the median value, the absolute minimum annual average flow occurred in 1999 (8.7 ft^3/s). Perhaps the combination of two low flow years (1998 yielded the maximum annual average flow of 97 ft^3/s) culminated to produce the extreme values observed in 2000.

Figure 27. Annual average temperature by site.

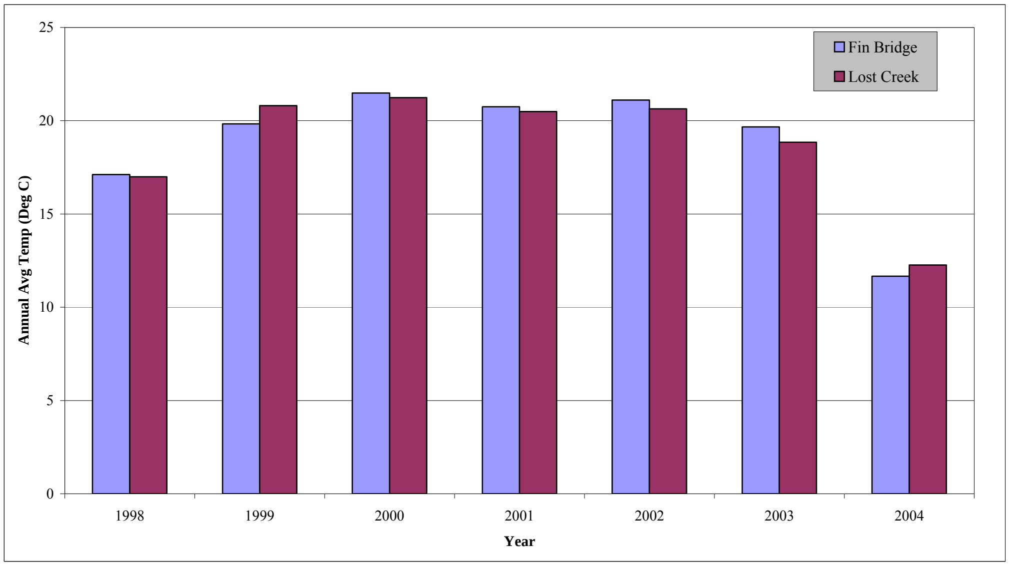


Figure 28. Annual average turbidity by site.

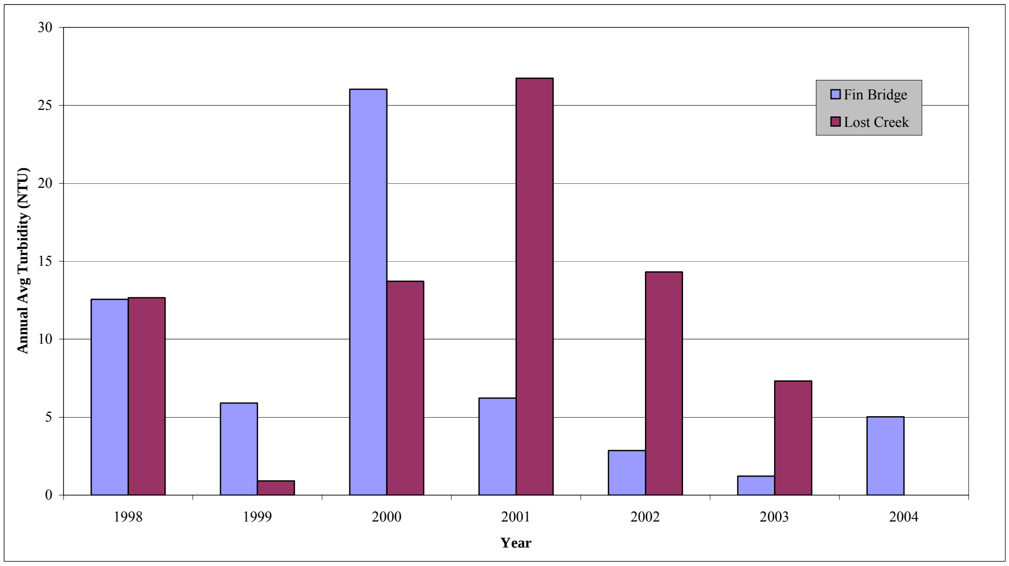
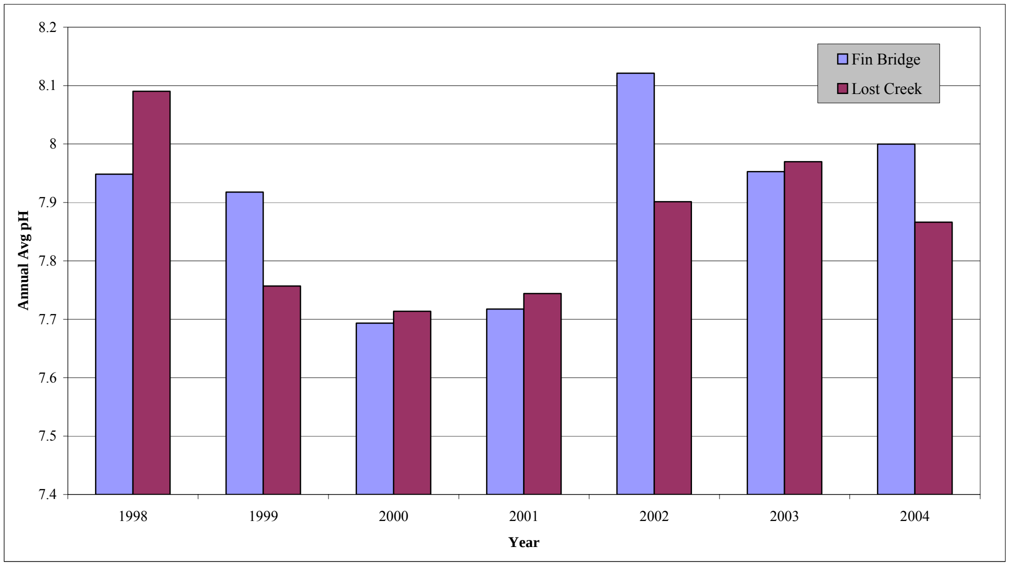


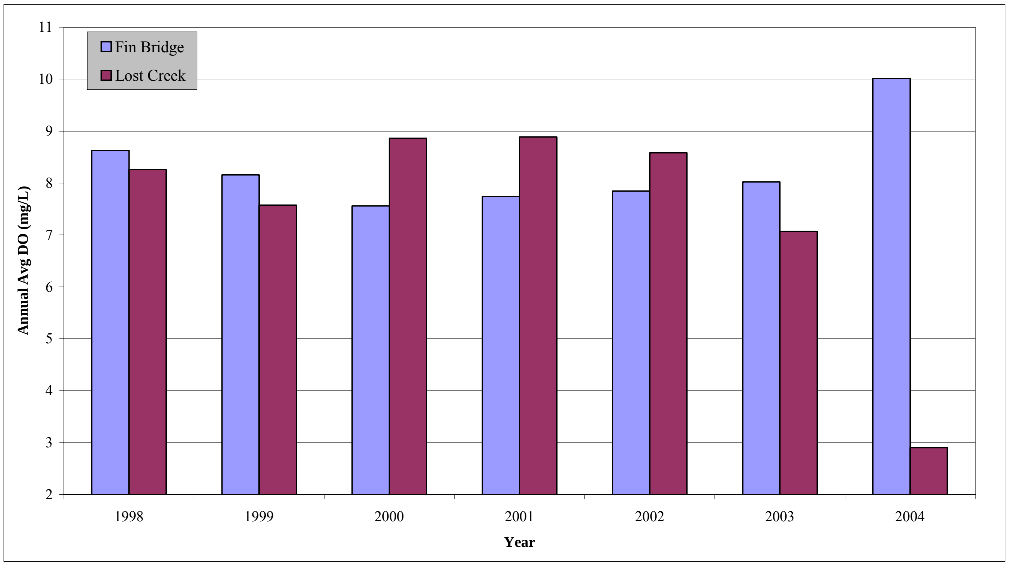
Figure 29. Annual average pH by site.



Analysis of changes by season yielded several slight, though statistically significant, temporal trends. Temperature may be decreasing in both summer and winter months at the Lost Creek site, but no long-term change is evident at Fin Bridge and there is no substantial change in annual average temperatures at Lost Creek.

A slight increasing (more basic) trend in pH, especially from low values observed in 2000, was observed and appears to be the result of increasing summer pH values. Conductivity yields an overall decrease at both sites in all three seasons. DO, though not changing over time at the Fin Bridge site, was decreasing in both summer and winter months from highs observed in 2000 and 2001 (Figure 30). The extremely low average DO value for Lost Creek in 2004 is the result of a long period of DO values <1 mg/L obtained during the last deployment presumed to be instrument error as daily average DO dropped from 7 mg/L to <1 mg/L in one day with no change observed in rainfall, flow or Fin Bridge DO.

Figure 30. Annual average DO by site.



Comparison to TCEQ Water Quality Standards

Segment-specific water quality standards (Table 7) exist for Barton Creek (segment #1430), as determined by the TCEQ (Texas Administrative Code, Title 30, Chapter 307). Evaluation of the physical parameter standards was conducted in accordance with TCEQ 303(d) guidelines (TCEQ 2003). Dissolved oxygen measurements were reduced to 24-hour daily averages before comparison to the water quality standard. Conductivity was reduced to an annual average before comparison to the water quality standard. Both temperature and dissolved oxygen measurements were restricted to the index period (March 15 – October 15), with between 50% and 66% of measurements made within the critical period (July 1 – September 30). Although there is no standard for conductivity, the TDS standard may be converted to a conductivity value using the 0.65 factor. All measurements made when Barton Creek flows dropped below the published 7Q2 (the low flow value for seven consecutive days with a predicted two-year return frequency) value of 0.1 ft^3/s were excluded.

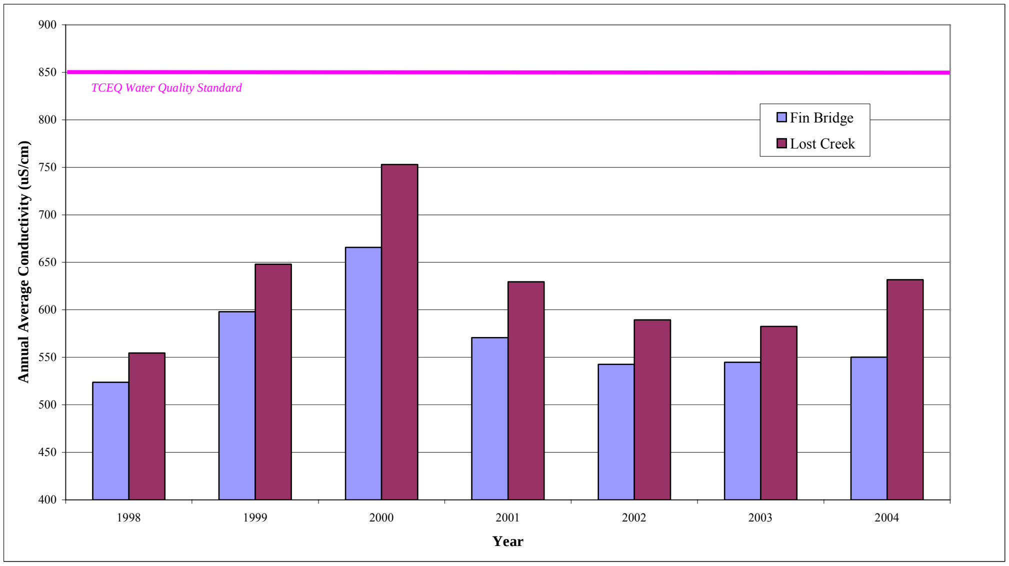
Table 7. Barton Creek water quality standards.

Parameter	**Criteria**	**Method of Evaluation**
Temperature	32°C	Values compared to standard; measurements must be within index period
Conductivity	850 µS/cm	Derived from TDS standard using 0.65 conversion factor; annual averages are compared to standard
pH	6.5 / 9.0	Values compared to minimum and maximum levels
Dissolved Oxygen	5 mg/L	24-hour averages compared to standard to determine # of exceedances; measurements must be within index period

Out of more than 260,000 measurements for pH, only 7 values were in excess of the water quality standard (5 below the minimum, 2 above the maximum). Barton Creek is not of concern for pH. In no year since 1998 has Barton Creek been of concern for temperature. The maximum percentage of samples exceeding the temperature standard at Fin Bridge in any one year is 0.65%. The maximum percentage of samples exceeding the temperature standard at Lost Creek is 7.1%, which occurred during a low-flow (flows less than 0.5 ft^3/s) period in July and August of 2001 in which 45 consecutive days yielded afternoon water temperature values in excess of the standard.

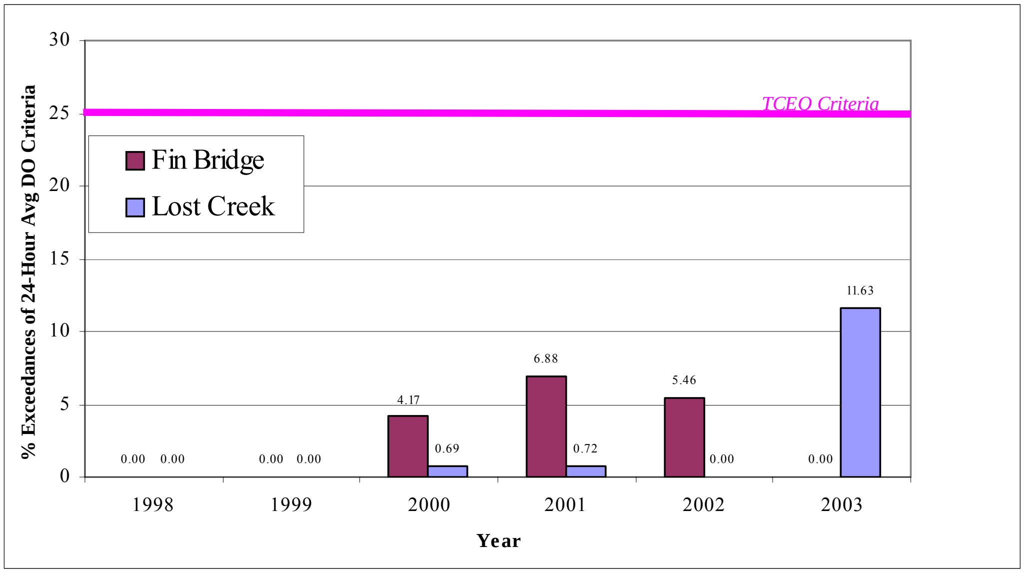
In no year since 1998 has Barton Creek been of concern for conductivity (Figure 31). The maximum annual average conductivity value of 753 µS/cm occurred in 2000 at Lost Creek. The Fin Bridge site yielded an overall average annual conductivity value of 571 µS/cm, and the Lost Creek site yielded an annual overall average of 627 µS/cm.

Figure 31. Annual average conductivity by site.



In no year since 1998 has Barton Creek been of concern for DO (Figure 32). The maximum percent exceedance in any year occurred at the Lost Creek site in 2003, when 10 out of 86 (11.6%) days yielded a 24-hour average DO value less than 5 mg/L.

Figure 32. Percent exceedance of 24-hour average DO by site and year.



Concurrent Sampling Events

Comparison of field measurements made concurrently with datasonde measurements are used to evaluate the accuracy of datasonde measurements (Table 8). Based on average %COV values between field and datasonde measurements, the parameters temperature, pH, conductivity and DO all yield low values (<10%) indicating acceptable accuracy of continuous instrumentation. Turbidity clearly yields unacceptable %COV values (>100) at both sites. This suggests that the turbidity data is not useful for quantitative purposes, and is of extremely questionable accuracy and precision. This correlates with evaluation of individual turbidity data streams that contain many large and unexplainable (no change in flow, rainfall or other parameters) jumps in turbidity values.

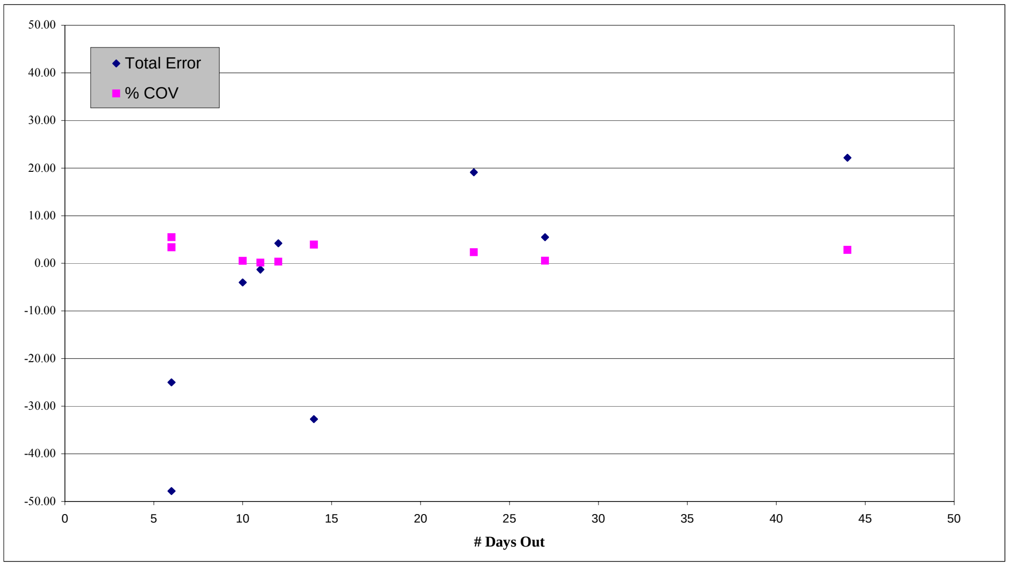
Table 8. Comparison of datasonde and field measurements by site and parameter.

Parameter	Avg Abs Error	Avg Total Error	Avg % COV	Min %COV	Max %COV
Lost Creek					
Temperature	0.409	-0.165	1.636	0.000	8.597
Turbidity	7.729	6.989	123.641	51.740	141.421
pH	0.204	0.019	1.836	0.000	4.183
Conductivity	27.795	-3.321	2.986	0.000	13.579
DO	0.713	0.135	6.264	0.883	15.920
Fin Bridge					
Temperature	0.474	-0.037	2.333	0.101	5.742
Turbity	27.918	27.248	107.458	24.595	141.421
pH	0.464	0.390	4.801	0.260	25.033
Conductivity	17.978	-6.644	2.178	0.158	5.488
DO	0.543	0.017	4.764	0.258	18.658

In addition to analysis of accuracy using concurrent sample results, total error and % COV values for each datasonde parameter were compared to number of days out by deployment, internal battery voltage and instantaneous flows at Lost Creek by Spearman correlation analysis.

Only total error (datasonde value minus measured field value) of conductivity at Fin Bridge was significantly correlated with number of days out ($n=9$, $p=0.03$, $\theta = 0.72$). Errors increased from more negative (lower datasonde values relative to measured field values) to more positive with increasing deployment lengths (Figure 33), potentially suggesting positive datasonde drift with increasing deployment lengths. No trend in total error of conductivity was observed at Lost Creek ($n=23$), and no trend in %COV of conductivity was observed at either site. Evaluation of individual events in which datasondes were cleaned by field staff following large storm events during an individual deployment indicate that sensor fouling lead to underestimation of conductivity values. Sensors would also be more likely to foul with increasing deployment lengths, which would not explain the high total error values observed when the Fin Bridge sensor has only been deployed for less than 10 days. Thus, no clear conclusions may be drawn from correlation between total error and deployment length for the Fin Bridge instrument.

Figure 33. Total error (datasonde-field measurement) and %COV of conductivity versus number of days out by deployment for the Fin Bridge site.

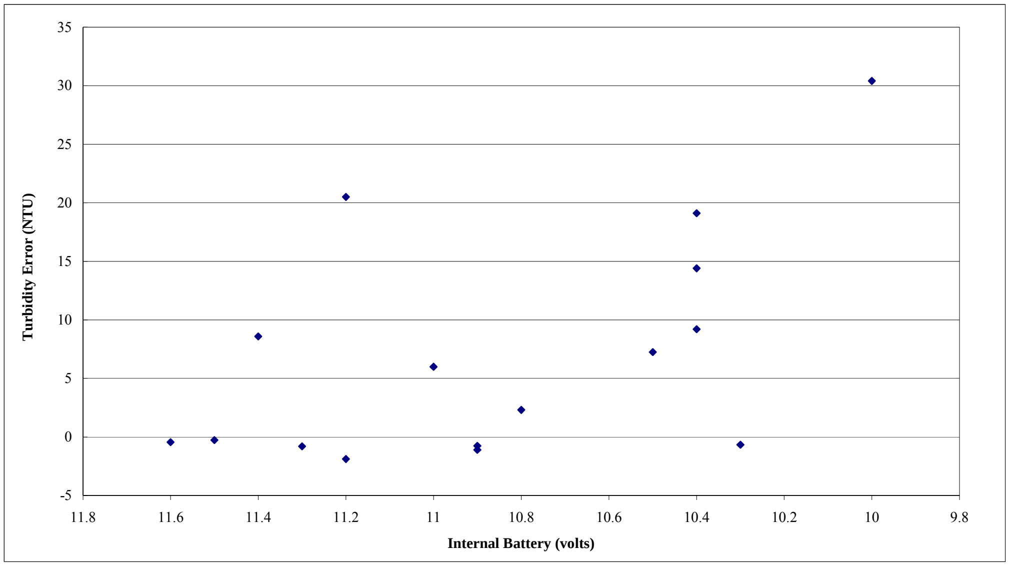


Although temperature %COV values at Lost Creek were significantly correlated with flow (n=17, p<0.01, θ = 0.70), the positive relationship was an artifact of a single %COV outlier occurring at high baseflow (%COV = 8.6, flow = 147 ft^3/s). Note that the mean temperature %COV value at Lost Creek is 1.6%. When this data point is removed from the analysis, the reduced correlation is no longer significant (p=0.11, θ = 0.42).

Creek flow also yielded a statistically significant relationship with total error of turbidity at Lost Creek (n=16, p<0.01, θ = 0.63), suggesting the reasonable relationship that turbidity errors increase with increasing flow as sensors become more fouled by passing debris and suspended solids. However, all concurrent turbidity measurements were made during non-storm flow conditions, and high baseflow could theoretically help to minimize sedimentation and occlusion of turbidity sensors by settling solids. No correlation between total error of turbidity and flow was evident at Fin Bridge, though storm impacts are expected to be more severe at the more downstream Lost Creek site. No correlation in %COV of turbidity versus flow was observed at either site. Though the observed relationship is logical, the lack of corroborating evidence leads to no clear conclusions.

Only the total turbidity error at the Lost Creek site was significantly correlated with internal battery voltage (n=16, p=0.03, θ=-0.50). As battery power drops, total turbidity error increases (Figure 34). No trend in total turbidity error was observed at Fin Bridge, and no trend in %COV values was observed at either site. Although the relationship is logical, the high total error and extremely high %COV values for turbidity at Lost Creek (123%) do not provide a clear breakpoint for delimiting accurate measurements from inaccurate ones (i.e., no clear internal battery voltage point exists at which total error values become unacceptable). More importantly, the high error values demonstrates the general lack of accuracy in datasonde turbidity measurements.

Figure 34. Total turbidity error at Lost Creek versus internal battery voltage based on concurrent sample events.



Number of Days Out

Percent change (as relative percent difference, RPD) between daily averages of each sampling day (relative to the previous day) was compared to number of days each datasonde had been deployed in an attempt to determine when datasonde sensors fail. The RPD of Lost Creek daily flow was used to isolate non-storm flow periods when change in daily datasonde values should be at a minimum.

In general, RPD values for each parameter are driven towards a central tendency of zero with increasing deployment lengths. One possible explanation rests in the nature of the drift or failure of the datasonde sensors. Rather than fluctuating wildly as sensors drift out of calibration, fluctuations may decrease as the sensors become more inaccurate over time.

Regression of all data (including storm flow values) versus number of days out yield no significant linear trends for any parameter at either site except internal battery voltage and turbidity. RPD of internal battery voltage ($p<0.01$) increases with increasing deployment length at both sites, as expected. RPD of turbidity weakly decreases as both Lost Creek ($p=0.045$, $r^2=0.003$) and Fin Bridge ($p<0.01$, $r^2=0.01$).

Pearson correlation analysis adjusting for change in Lost Creek flow (partial for flow) yields similar results. Though statistically significant, the correlation between both turbidity (Lost Creek $\theta = -0.06$, Fin Bridge $\theta = -0.08$) and internal battery voltage (Lost Creek $\theta = 0.19$, Fin Bridge $\theta = 0.11$) with increasing deployment length is weak, and yields no clear breakpoint for determining sensor failure by number of days out.

Recommendations

Programmatic determination of time at which datasonde sensors fail is difficult, and all future datasonde deployments must be followed by well-documented post-calibration procedures with results carefully logged to determine which sensors have definitely drifted out of calibration. It is crucial that datasondes not be cleaned or placed in off-site water when removed from the field prior to post-calibration in the laboratory to insure an accurate post-calibration.

Even with post-calibration to determine which sensors are no longer reliable at the end of the deployment, it is still difficult to definitively determine at what point in the preceding deployment the instrument drifted out of calibration. Thus, reduced deployment lengths would not only help to minimize the amount of data to be "disqualified" for failure to sufficiently post-calibrate, but also lead to a potential reduction in sensor failure (based on the reasonable assumption that sensor failure is likely to increase with length of deployment).

The lack of reliable turbidity measurements suggests that it is of little use, and turbidity sensors could potentially be excluded from future monitoring equipment purchases. Though the high variability (> 100% COV between concurrent field measurements and datasonde measurements) makes turbidity unlikely to be accurate, field personnel should continue to properly calibrate and record turbidity measurements with datasonde deployments. Little additional effort would be required, and potentially some small amount of information can still be gleaned from the data.

Baseline spatial, seasonal and temporal variation have been well-documented at these two locations on Barton Creek. Although datasondes show that Lost Creek may be more impacted from development than Fin Bridge, the true nature and source of these impacts cannot be determined by datasonde instrumentation. This, in combination with the lack of clear temporal trends and the absence of observations in excess of applicable water quality standards, suggest a reduction in the frequency and duration of datasonde deployments at these sites on Barton Creek. Several other alternatives exist:

- Continue deployment at these two locations, but only for periodic screening purposes. If deployments were reduced to 24-hour time periods, the data could be submitted to TCEQ for inclusion in the 303(d) evaluation and 305(b) inventory (only successfully post-calibrated 24-hour deployments are acceptable. Continued monitoring at these locations, even only for several 24-hour periods per year, would not orphan the robust historical dataset but would allow the datasondes to be used at other places on Barton Creek or even other creeks throughout the Austin area.
- Reduce the time periods when datasondes are deployed to target times of maximum stress. Monitoring only during summer low flow periods would be more likely to observe low DO, high conductivity phenomena. This would free the datasondes for deployment in other locations. Routine measurements by field staff could be used to trigger the re-deployment of datasondes on Barton Creek if extreme values were encountered in the future.
- Continue the deployments of datasondes for continuous monitoring, but at other locations on Barton Creek or even other creeks. This strategy would expand our knowledge of the daily fluctuations of the physical parameters at other sites, but would tend to isolate the historical data at these two Barton sites.

Conclusions

Seasonality:

- Temperature (and water depth) show a pattern of two seasonal groups in Barton Creek with a transitional period between seasons. Winter is defined from November to March and Summer from May to September, with April and October forming the transitional periods.

Site Differences:

- Lost Creek maintains higher monthly mean conductivity all year long and generally higher mean turbidity, suggesting a potential impact from the development located between the two sites.
- Higher DO values at Lost Creek may be the result of an increased algal community supported by a higher nutrient load than is available at Fin Bridge.
- Fin Bridge yields a wider range of pH values than Lost Creek.

Correlation with Flow:

- Temperature and conductivity are negatively related to flow. Depth, pH and DO are positively related to flow. Groundwater influences may be more evident at the Lost Creek site based on pH and conductivity fluctuations with flow.

Correlation with Rainfall:

- No strong patterns of correlation with antecedent rainfall where observed. Either summation of antecedent rainfall, even over periods ranging from 15 minutes to 14 days, is an invalid technique, or rainfall affects are not conspicuous in physical parameter data.

Individual events:

- Analysis of individual storm events clearly demonstrate the response of each parameter to run-off. As expected, conductivity decreases following storm events while pH and turbidity increase. Despite an expected decrease in DO following storm events as an oxygen demand is exerted by the organic matter delivered to the creek with storm runoff, DO appears generally unaffected by storm flow. Response of temperature to rainfall events depends on time of year, but generally decreases with rainfall.

Temporal Trends:

- No clear temporal trends are evident, though 2000 was yielded the poorest water quality of all years studied. Although 2000 yielded an annual average flow below the median value, the absolute minimum annual average flow occurred in 1999 (8.7 ft^3/s). Perhaps the combination of two low flow years (1998 yielded the maximum annual average flow of 97 ft^3/s) culminated to produce the extreme values observed in 2000.

TCEQ Water Quality Standards:

- Comparison of continuous monitoring data to TCEQ water quality standards indicate that Barton Creek was not of concern for temperature, pH, conductivity (as a surrogate for TDS), or dissolved oxygen from 1998 to 2003.

Concurrent Results:

- Turbidity is of extremely questionable accuracy when datasonde instrumentation are compared to concurrent instantaneous field measurements. This correlates with evaluation of turbidity data streams that contain many large and unexplainable (no change in flow, rainfall or other parameters) jumps in turbidity values.

Number of Days Out:

- As deployment length increases, datasonde sensors may drift out of calibration or become more inaccurate even though the percent change in daily mean values decreases toward zero.

References

TCEQ. 2003. Guidance for Assessing Texas Surface and Finished Drinking Water Quality, 2004. Texas Commission on Environmental Quality, Office of Compliance and Enforcement, Monitoring Operations Division, Surface Water Quality Monitoring Program.

Appendix

Inventory of Datasonde Deployments by Site.

Lost Creek

Lost Creek Instrument	Start Date	Start Time	End Date	End Time
DataSonde4 34481	10/7/1998	180000	11/4/1998	100000
DataSonde4 34481	11/9/1998	190000	12/3/1998	161500
DataSonde4 34481	12/7/1998	180000	1/7/1999	100000
DataSonde4 34481	1/15/1999	180000	2/12/1999	100000
DataSonde4 34481	2/17/1999	180000	3/17/1999	100000
DataSonde4 34481	3/18/1999	160000	4/15/1999	100000
DataSonde4 34481	4/16/1999	180000	5/13/1999	154500
DataSonde4 34481	5/14/1999	180000	6/10/1999	133000
DataSonde4 34481	6/11/1999	180000	7/8/1999	100000
DataSonde4 34481	7/27/1999	180000	8/31/1999	100000
DataSonde4 34481	9/2/1999	180000	10/1/1999	100000
DataSonde4 34481	10/14/1999	180000	11/17/1999	100000
DataSonde4 34481	11/22/1999	180000	12/27/1999	100000
DataSonde4 34481	12/30/1999	180000	1/31/2000	100000
DataSonde4 34481	2/3/2000	180000	2/28/2000	234500
DataSonde4 34481	3/7/2000	180000	4/5/2000	100000
DataSonde4 34481	4/6/2000	180000	5/3/2000	100000
DataSonde4 34481	5/3/2000	183000	6/7/2000	100000
DataSonde4 34481	6/8/2000	183000	7/5/2000	100000
DataSonde4 34481	7/7/2000	180000	8/9/2000	100000
DataSonde4 34481	8/9/2000	180000	9/6/2000	100000
DataSonde4 34481	9/7/2000	180000	10/4/2000	100000
DataSonde4 34481	10/10/2000	180000	11/8/2000	100000
DataSonde4 34481	11/8/2000	184500	12/5/2000	171500
DataSonde4 34481	12/6/2000	184500	1/3/2001	100000
DataSonde4 34481	1/3/2001	180000	2/7/2001	100000
DataSonde4 34481	2/8/2001	180000	3/6/2001	163000
DataSonde4 34481	3/8/2001	180000	4/4/2001	100000

DataSonde4 34481	4/5/2001	120000	5/2/2001	100000
DataSonde4 34481	5/7/2001	180000	6/6/2001	100000
DataSonde4 34481	6/20/2001	180000	7/25/2001	81500
DataSonde4 34481	7/25/2001	180000	8/29/2001	100000
DataSonde4 34481	9/4/2001	180000	10/9/2001	130000
DataSonde4 34481	10/10/2001	180000	11/7/2001	100000
DataSonde4 34481	11/7/2001	183000	12/12/2001	100000
DataSonde4 34481	12/12/2001	180000	1/8/2002	94500
DataSonde4 34481	1/8/2002	180000	2/6/2002	100000
DataSonde4 34481	2/7/2002	133000	3/7/2002	100000
DataSonde4 34481	3/11/2002	180000	5/8/2002	100000
DataSonde4 34481	5/13/2002	180000	6/26/2002	100000
DataSonde4 34481	6/27/2002	180000	8/6/2002	164500
DataSonde4 34481	8/7/2002	180000	9/11/2002	100000
DataSonde4 34481	9/17/2002	180000	10/16/2002	100000
DataSonde4 34481	10/17/2002	180000	11/19/2002	110000
DataSonde4 34481	12/4/2002	180000	1/8/2003	100000
DataSonde4 34481	1/23/2003	180000	3/4/2003	100000
DataSonde4 34481	3/27/2003	120000	4/30/2003	100000
DataSonde4 34481	5/2/2003	180000	5/29/2003	150000
MiniSonde 4a 38103	9/12/2003	180000	10/26/2003	173000
MiniSonde4a 053003	1/7/2004	180000	2/4/2004	100000

Fin Bridge (Barton Creek Boulevard).

Fin Bridge Instrument	Start Date	Start Time	End Date	End Time
DataSonde4 34480	07-Oct-1998	180000	04-Nov-1998	100000
DataSonde4 34480	09-Nov-1998	183000	03-Dec-1998	180000
DataSonde4 34480	07-Dec-1998	180000	07-Jan-1999	100000
DataSonde4 34480	15-Jan-1999	180000	12-Feb-1999	100000
DataSonde4 34480	17-Feb-1999	180000	06-Mar-1999	144500
DataSonde4 34480	18-Mar-1999	160000	15-Apr-1999	100000
DataSonde4 34480	16-Apr-1999	180000	13-May-1999	165000
DataSonde4 34480	14-May-1999	180000	10-Jun-1999	140000
DataSonde3 31526	27-Jul-1999	180000	31-Aug-1999	100000
Datasonde4 34962	14-Oct-1999	180000	17-Nov-1999	100000
Datasonde4 34962	22-Nov-1999	180000	27-Dec-1999	100000
DataSonde4 34480	30-Dec-1999	180000	31-Jan-2000	100000
DataSonde4 34480	03-Feb-2000	180000	28-Feb-2000	234500
DataSonde4 34480	07-Mar-2000	180000	05-Apr-2000	100000
DataSonde4 34480	06-Apr-2000	180000	03-May-2000	100000
DataSonde4 34480	03-May-2000	180000	07-Jun-2000	100000
DataSonde4 34480	08-Jun-2000	180000	05-Jul-2000	100000
DataSonde4 34480	07-Jul-2000	180000	09-Aug-2000	100000
DataSonde4 34480	09-Aug-2000	180000	06-Sep-2000	100000
DataSonde4 34480	07-Sep-2000	180000	04-Oct-2000	100000
DataSonde4 34480	10-Oct-2000	183000	08-Nov-2000	100000

DataSonde4 34480	08-Nov-2000	180000	06-Dec-2000	94500
MiniSonde 4a 38103	06-Dec-2000	180000	03-Jan-2001	100000
Datasonde4 34962	03-Jan-2001	180000	06-Feb-2001	104500
DataSonde4 34480	06-Mar-2001	180000	04-Apr-2001	100000
DataSonde4 34480	05-Apr-2001	120000	02-May-2001	100000
DataSonde4 34480	07-May-2001	180000	06-Jun-2001	100000
DataSonde4 34480	20-Jun-2001	180000	25-Jul-2001	80000
DataSonde4 34480	25-Jul-2001	180000	21-Aug-2001	121500
DataSonde4 34480	04-Sep-2001	180000	09-Oct-2001	130000
DataSonde4 34480	10-Oct-2001	180000	07-Nov-2001	100000
DataSonde4 34480	07-Nov-2001	181500	12-Dec-2001	93000
DataSonde4 34480	12-Dec-2001	180000	28-Dec-2001	144500
DataSonde4 34480	08-Jan-2002	180000	28-Jan-2002	84500
DataSonde4 34480	07-Feb-2002	131500	24-Feb-2002	193000
DataSonde4 34480	11-Mar-2002	180000	08-May-2002	100000
DataSonde4 34480	13-May-2002	180000	26-Jun-2002	100000
MiniSonde 35033	28-Jun-2002	163000	15-Jul-2002	170000
DataSonde4 34480	07-Aug-2002	180000	11-Sep-2002	100000
DataSonde4 34480	17-Sep-2002	180000	16-Oct-2002	100000
DataSonde4 34480	17-Oct-2002	180000	19-Nov-2002	113000
DataSonde4 34480	04-Dec-2002	180000	08-Jan-2003	100000
DataSonde4 34480	23-Jan-2003	180000	04-Mar-2003	100000
DataSonde4 34480	27-Mar-2003	120000	30-Apr-2003	100000
DataSonde4 34480	02-May-2003	180000	29-May-2003	144500
DataSonde4 34480	12-Sep-2003	180000	29-Oct-2003	100000
DataSonde4 34480	07-Jan-2004	180000	04-Feb-2004	100000