Chemical and biological responses of urban streams to sanitary sewer overflows in Austin, TX

SR-14-09, December 2014

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Abstract

In 2008, more than 30 billion gallons of wastewater flowed through 2,650 miles of sanitary sewer lines maintained by the City of Austin, TX. On average there are 150 reportable wastewater releases to Austin streams annually. Pollutant concentrations of untreated wastewater (e.g., 5-day biochemical oxygen demand > 200 mg/L and ammonia-nitrogen > 20 mg/L as N) are orders of magnitude higher than ambient stream concentrations. Although the effect of untreated wastewater on streams has been studied for over a hundred years, spatial and temporal effects from small pulse events on aquatic ecosystem structure and function have not been well documented. Three spill events of varying magnitudes were studied on three intermittent urban streams, documenting chemical and biological responses using an upstream-downstream approach over a 2-month recovery period.

Water chemistry spatial differences in relation to sanitary sewer overflow locations were less severe than expected, recovering generally within 2 weeks. However, ecological response including macroinvertebrate and diatom community effects was dramatic both spatially and temporally, with recovery to background conditions only occurring at one of the study streams after two months of monitoring, and degradation of benthic macroinvertebrate communities observed at extended distances downstream of the spill location. Discrete functional changes in the macroinvertebrate community were consistent among study streams. Diel dissolved oxygen ranges were reduced at spill affected sites, falling below the state aquatic life average criteria of 5 mg/l in some locations, but recovered fairly quickly. The duration of the wastewater release event, which varied among the study streams, appears to be more important than the magnitude of the spill in determining stream impacts. Results from this study suggest that sanitary sewer overflows are a significant stressor in urban streams, causing more extensive and longer-term ecological degradation than was previously thought.

Introduction

In 2008, more than 30 billion gallons of untreated wastewater flowed through 2,650 miles of sanitary sewer lines maintained by the City of Austin, TX. On average, there are 150 reportable releases by sanitary sewer overflows of untreated sewage to Austin streams annually. Pollutant concentrations of this wastewater are orders of magnitude higher than ambient stream concentrations (e.g., 5-day biochemical oxygen demand > 200 mg/L and ammonia-nitrogen > 20 mg/L). In addition, due to the size and intermittent flow regime of most of these receiving streams, there is very little dilution, resulting in wastewater dominated flows for hours, to days, even to months, depending on spill dynamics.

The ecological effects of untreated wastewater on streams has been studied for over a hundred years (Wiebe 1927, Hynes 1960, Odum 1985), primarily targeting direct discharges to larger receiving waters and leading to the Clean Water Act of 1972. However, spatial and temporal effects from small pulse and chronic leakage events on ecosystem structure and function in smaller streams has not been well documented (but see Cloern and Oremland 1983, Balmforth 1990, Quinn and Hickey 1993, Mallin et al 2007). The result of these types of events has recently been included in what has been coined the "urban stream syndrome" (Walsh et al. 2005)(Wenger et al. 2009), which composites the wide range of stressors that urban development brings to stream systems. Our goal in this study was to measure the spatial (extent) and temporal (recovery) effects of individual sewage spill events in urban stream systems.

Three sewage spill events of varying magnitude and scale were studied on three intermittent streams. We documented chemical and biological responses to these events using an upstream-downstream approach over a 2-month recovery period. We hypothesized that the volume of a spill would increase the distance downstream that effects would be observable and increase the time it would take for a stream to recover to background conditions. We also hypothesized that biological or functional effects from these spills would be larger spatially and temporally than chemical effects.

In all three spills events, city staff responded in a similar fashion: stop the sewage from getting in the creek, vacuum/pump out all pooled areas that had evidence of sewage inputs, and flush and remove all solids from the bed of the creek and overland spill areas. These actions are important to mitigating the impact of the sanitary sewer overflow to the receiving water, but even with these remedial actions biological and chemical impacts occur as assessed by this study.

Methods

Site/Spill Selection

Staff elected *a priori* to target three sanitary sewer overflows (spills) during a defined time period for this study due to resource and time limitations. Spill events were reviewed upon notification and selected for study based on a series of criteria:

- Did the spill reach a flowing stream?
- Was the stream supporting a relatively stable ecosystem (i.e. maintained baseflow for at least the previous 3 months)?
- Was the spill relatively large (> 10,000 gallons)?

The spill events studied (Table 1) occurred in three watersheds in urban Austin in 2007. The first spill, on February 20, 2007, occurred when a sanitary sewer blockage during a storm event caused approximately 40,000 gallons of sewage to back up and overflow, out of a manhole, into the headwaters of Blunn Creek. This creek would be classified as intermittent, with some seeps and small springs in the area maintaining a relatively stable benthic community most of the year. Development in the catchment is relatively dense commercial and multi-family residential, with total impervious cover at about 40%. Post-spill monitoring was initiated the day after the event, on February 21, 2007, but prematurely ended the recovery period when a storm event occurred on March 11, 2007, scoured the creek.

The second spill, estimated at 50,000 gallons, occurred on August 27, 2007, when a sanitary sewer blockage occurred during a small storm event, resulting in an overflow of sewage from a series of manholes to a small, spring-fed tributary to Bull Creek (Stillhouse Hollow) that is also a City of Austin nature preserve, with a known small population of Jollyville Plateau salamanders (*Eurycea tonkawae*). Development around the preserve is relatively dense single family residential (~20% total impervious cover) but the topography has kept the creek and riparian buffers somewhat protected from urban stressors and encroachment. Monitoring was initiated on August 28, 2007, and completed on October 16, 2007, seven weeks after the spill occurred.

The third spill was reported on October 29, 2007, apparently weeks after it had initiated based on the biological communities observed in the creek. An 8 inch sanitary sewer main that crossed the creek was sheared off during a storm event, resulting in at least 50,000 gallons of sewage discharge into the headwaters of Williamson Creek over a period of at least 2 weeks. When the spill was discovered, there were already mature sewage fungi developed (*Sphaerotilus* spp.) as well as large colonies of blood midges (*Chironomus* spp.), both of which require weeks to mature. The catchment to this reach of Williamson Creek is dominated by single-family residential development with light commercial and transportation land uses with a total impervious cover of about 20%. The City of Austin (COA) has a long-term routine monitoring site immediately upstream of this spill event location (Williamson Creek at Hwy 71, COA# 490) and the U.S. Geological Survey (USGS) has a long-term monitoring station just downstream of where the spill occurred (Williamson Ck at Oak Hill, USGS# 08158920), both of which informed this spill investigation significantly. Spill monitoring was initiated on November 1, 2007, and concluded on January 3, 2008, nine weeks following the discovery of the event.

Table 1. Sanitary sewer overflow (spill) events selected for comprehensive evaluation, including date of spill, estimated volume of spill and known duration of the event.

Location	Catchment Size (acres)	Date of Spill	Volume (gal)	Duration
Blunn Creek at Woodward Drive	300	20-Feb-07	40,000	12+ hours
Bull Creek at Stillhouse Hollow	250	27-Aug-07	50,000	24+ hours
Williamson Creek at Highway 71	2000	30-Oct-07	50,000	14+ days

Study Design

Due to the uni-directional character of flowing streams and since these sanitary sewer overflow events essentially function as a point source, pulse event, we chose an upstream-downstream approach which bracketed the location of the spill, and added a farther downstream location to look at spatial recovery dynamics (Fig 1). The Above-Spill site was selected as the most immediate upstream riffle/pool combination that was hydrologically separate from the location of the spill. The At-Spill site was the immediate riffle/pool combination downstream of the point at which the spill discharged into the creek. The downstream (Below) site was located one stream reach (20x bankfull-width) downstream of the spill location to normalize this location relative to the spill location among the three study spills.

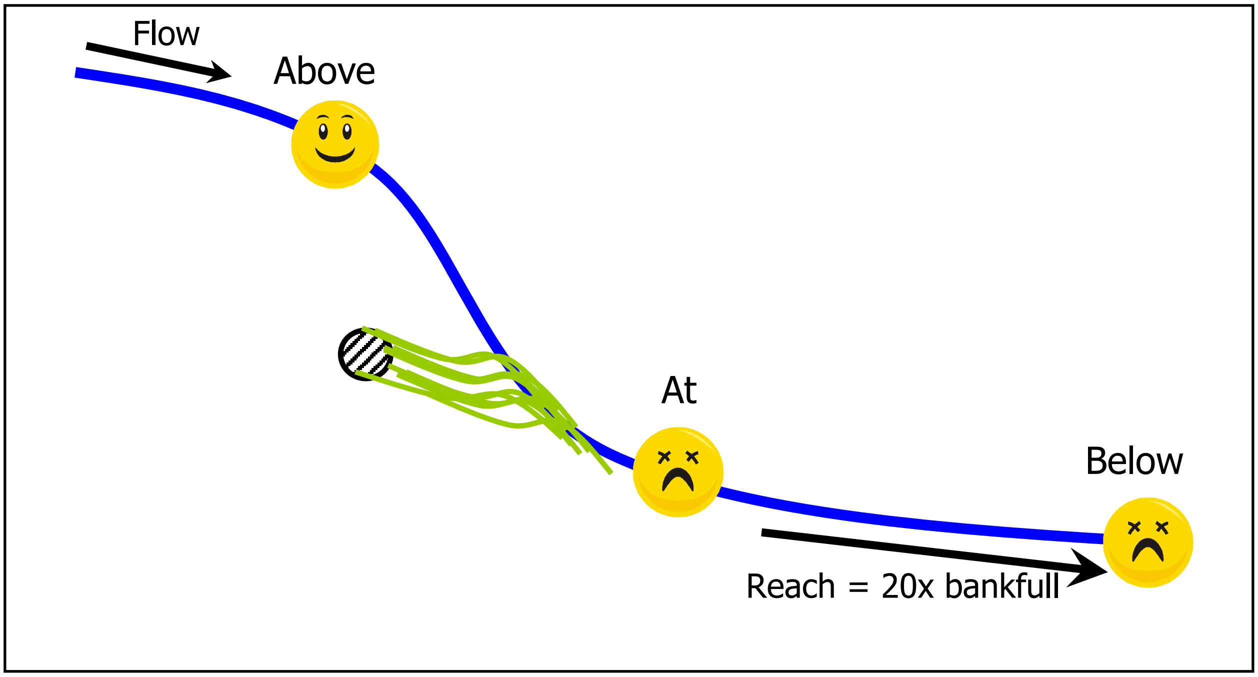

Figure 1. Monitoring locations at three spill events: upstream of the spill (Above), at the spill (At) and downstream of the spill (Below). The Below spill location was one reach-length (20x bankfull-width) below the location of the spill.

A 5-event monitoring schedule was selected to capture the temporal dynamics of recovery at the study sites. Our initial reconnaissance occurred within two days (48 hours) of the spill occurring and included basic physio-chemical parameters and a diel (24-hour) oxygen assessment. Within one week of the spill, we collected a comprehensive suite of biological, chemical and physical parameters (Table 2), followed by three more of these sampling events at 3-, 5-, and 7-weeks. This time frame allowed us to document potential recovery of the range of ecological measures selected, from short term chemical changes to the longer-term benthic macroinvertebrate community succession.

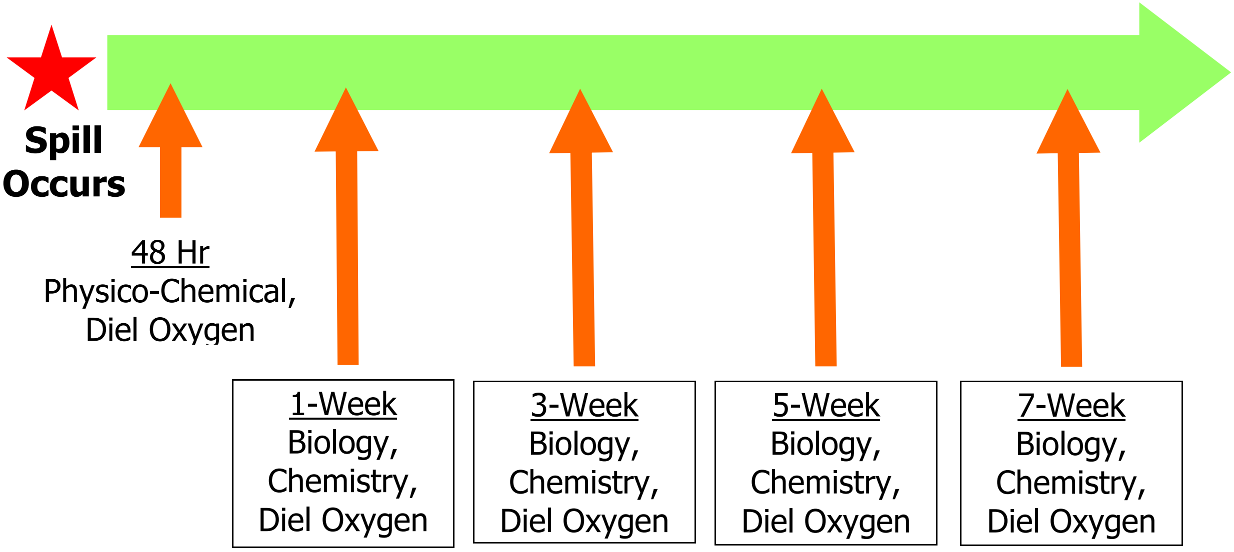

Figure 2. Temporal approach to spill monitoring which includes an initial reconnaissance survey after one week, followed by four intensive events at 1-, 3-, 5- and 7-weeks after the spill occurred.

Data Collection

A range of environmental measures (Table 2) were sampled at each of the three sampling locations based on the temporal approach detailed in Figure 2.

Table 2. Sampling Regime Summary. HQI=Habitat Quality Index (EPA 1999).

Time after Spill	**EPA HQI**	**Diel Dissolved Oxygen**	**Discharge**	**Water Chemistry**	**Riffle Bugs**	**Pool Bugs**	**Diatoms**	**Photos, Field Notes**
w/in 24 hr	X	X	X	X				X
1 week		X	X	X	X	X	X	X
3 weeks		X	X	X	X		X	X
5 weeks		X	X	X	X		X	X
7 weeks	X	X	X	X	X	X	X	X

The Habitat Quality Index (Barbour et al. 1999), a visually based field method was used to assess general instream and riparian habitat according to standard COA protocol (COA 2012). This data is collected only at the initiation of the sampling and then at the very end to document any variation in physical habitat that may have occurred during the monitoring period.

Diel (24-hour) dissolved oxygen is measured *in-situ* using a Hach Hydrolab datasonde with 15 minute collection intervals. All calibration, deployment and data management is carried out according to standard COA procedures (COA 2012) and generally consistent with TCEQ procedures (TCEQ 2012). In addition to dissolved oxygen, temperature (ºC), pH, and conductivity (µS/cm) are also measured and recorded with this same equipment. Diel monitoring was performed five times from initiation to completion of the 7-week recovery period.

Discharge (cubic feet per second, CFS) was measured at each site visit using a Marsh-McBirney flow meter according to standard COA methods (COA 2012).

Water samples were collected at all site visits at each of the three study sites and analyzed for nitrate plus nitrite as N (NO3 +NO2), orthophosphorus as P, and ammonia as N (NH3) by the Lower Colorado River Authority (LCRA) Environmental Laboratory by NELAP-accredited methods. *Escherichia coli* (E.coli) was measured using the IDEXX Colilert Quanti-Tray/2000 method by COA staff in our laboratory.

Benthic macroinvertebrates were sampled four times in riffle habitat throughout the study period and twice in pool habitat, at week 1 and at week 7 (Table 2). Riffle habitat was sampled using a Surber Sampler according to standard COA methods (COA 2012). Pool organisms were sampled via composite grabs of pool sediments using standard sediment sampling and elutriation methods (COA 2012). Benthic macroinvertebrate organisms were generally identified to the genus level by COA staff using standard taxonomic keys.

Diatom communities were sampled by rock scraping of known areas from riffle substrates four times throughout the study period according to standard COA methods (COA 2012) and were processed and identified to the species level in community counts of 500 organisms (Winsborough Consulting).

Analysis

Differences between sites were evaluated using the non-parametric paired comparison Wilcoxon signed-rank test, grouped by parameter and spill event. Because of the low number of samples, an alpha value of 0.10 was used to determine significant differences.

Selected metrics for diatom and benthic macroinvertebrate data sets were calculated following standard methods outlined in COA (2012) Standard Operating Procedures Manual.

Boxplots for evaluating differences between sampling locations for a spill event were generated using SAS PROC BOXPLOT. The boxes represent the interquartile range, the horizontal line represents the median, the black (filled) dot represents the mean, whiskers represent the minimum and maximum values, and if applicable the white (unfilled) dots represent outliers.

Control charts (Shewhart 1931) were used to visually evaluate temporal changes by site for each spill event. Data points are shown as solid lines, while the upper (75th) and lower (25th) quartiles for the upstream reference site (Above Spill) are used as control limits and displayed as dashed lines.

Results and Discussion

Water Chemistry

Spatial

Water column nutrient site differences among the three study locations were minimal, but did show some spill effects (Appendix A). Generally, nitrate during the study period was lower

Below Spill than at either of the upstream sites (Figs 3a-c), and there was no difference between Above Spill and At Spill locations, except at the Williamson Creek spill, where all three sites were different from each other.

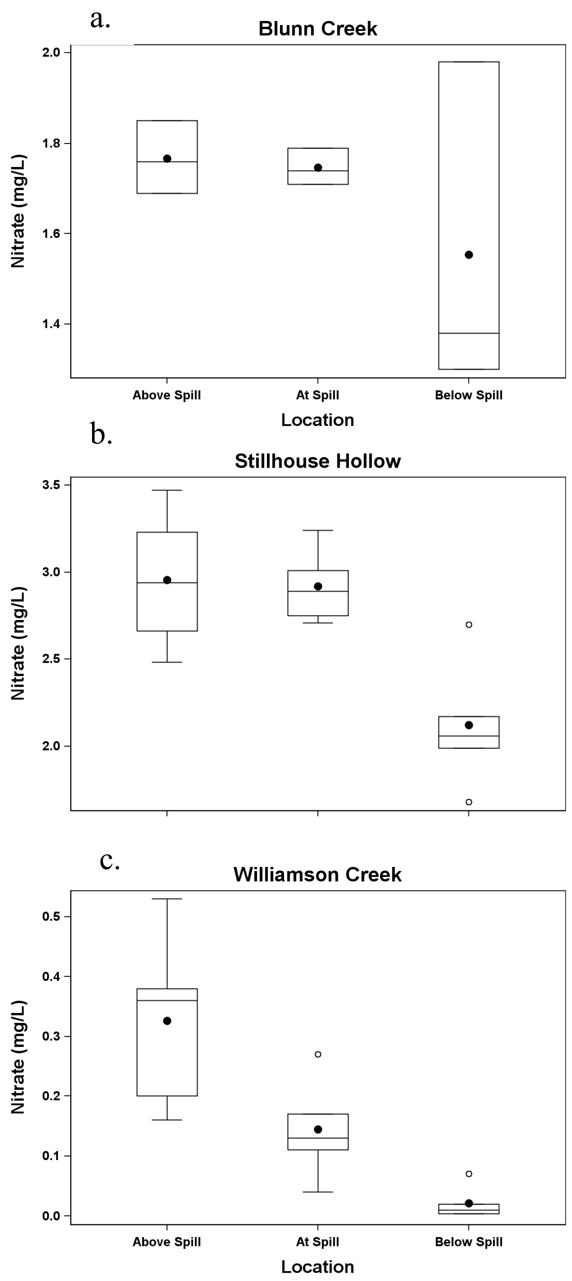

Figure 3a-c. Nitrate+Nitrite as N concentrations during 3 spill events, at 3 locations, during the 7 week monitoring period.

Ammonia had a very different pattern than nitrate, generally going from the lowest concentration Above Spill to the highest concentration Below Spill (Fig 4a-c). This pattern generally reflects the low levels of background ammonia in most Austin streams (COA 2011) that was consistently documented at all Above Spill locations (<0.05 mg/L) and the large influx of ammonia-nitrogen forms from the untreated sewage pulses (> 20 mg/L, COA unpublished data). Although Below Spill had some high concentrations documented at all three spill locations, there was no significant difference between Below Spill and the other two study locations (Appendix A).

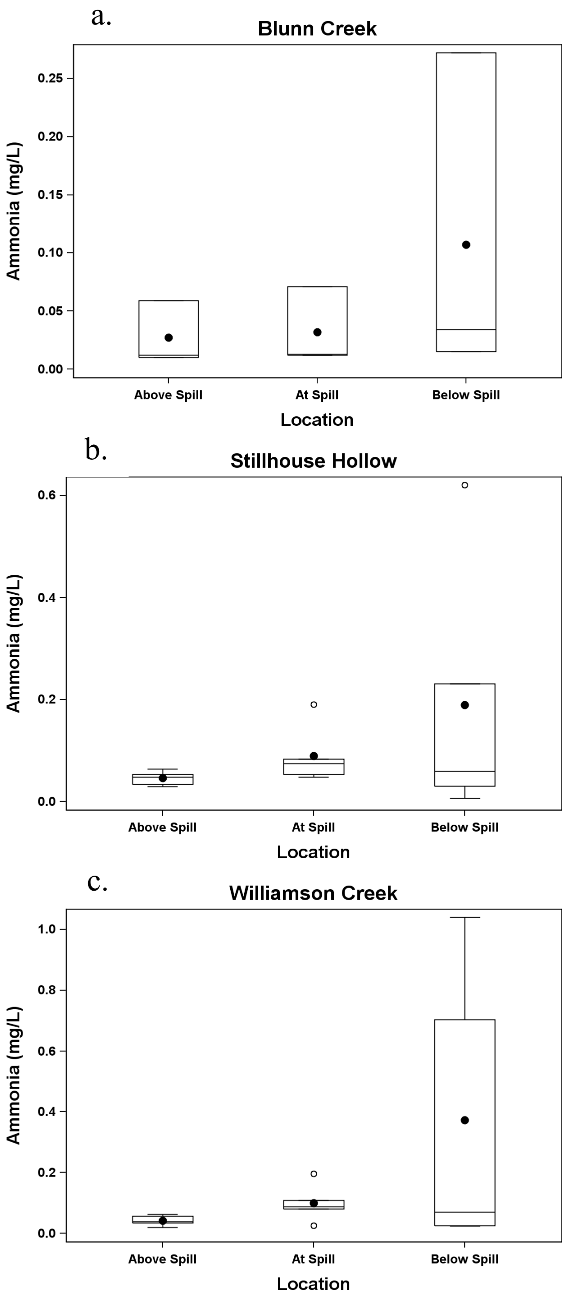

Figure 4a-c. Ammonia as N concentrations during 3 spill events, at 3 locations, during the 7 week monitoring period.

Orthophosphorus spatial patterns were similar to ammonia, with some higher concentrations Below Spill. However, there was no significant difference in means at any of the three study locations (Figs 5a-c).

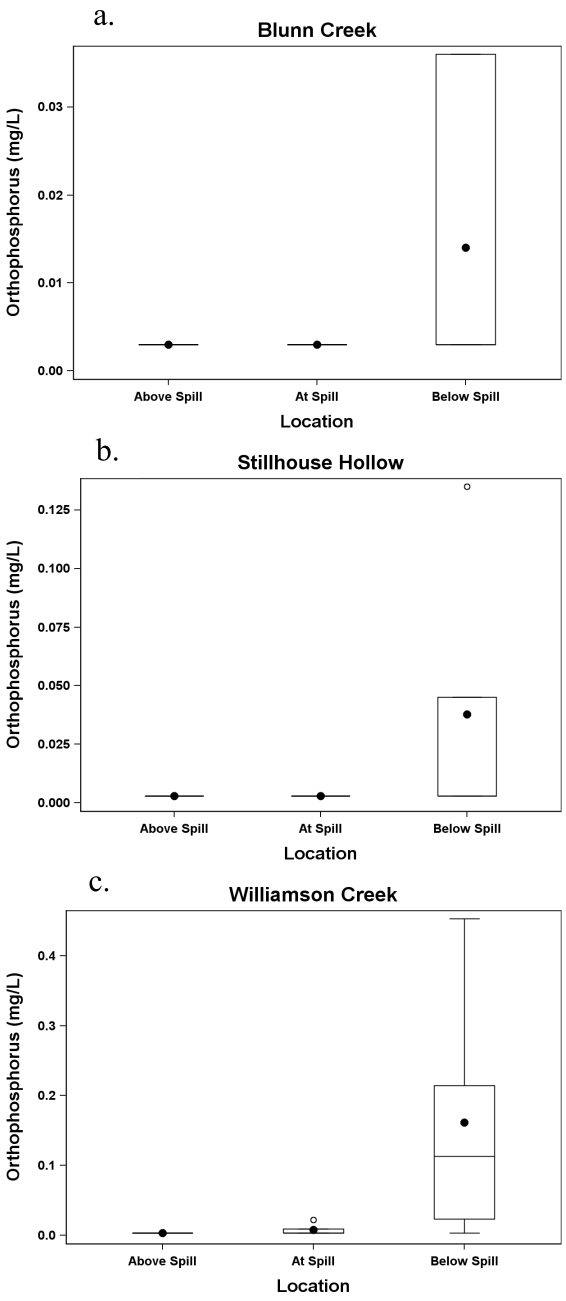

Figure 5a-c. Orthophosphorus as P concentrations during 3 spill events, at 3 locations, during the 7 week monitoring period.

There were no differences in mean *E. coli* concentrations among study sites at any of the three spill locations (Appendix A). Although values were generally higher At Spill and Below Spill than Above Spill, the means were not different during the study period due to high variability in this data set.

Temporal

In order to visualize the temporal component of this study design, a control chart approach was used that shows the inter-quartile range (25th-75th percentile) of the upstream reference site (in green dotted lines) compared to the temporal pattern of the immediately downstream At Spill site (in blue) and the end-of-reach Below Spill site (in red). Generally, for all three nutrients measured (NO3+NO2, NH3, OP) there was a temporal recovery response at both of the downstream sites compared to the reference site during the 7-week study period. For nitrate (Fig. 6a-c), there was generally a positive increasing trend over time, with relatively low concentrations immediately following the spill, and increasing concentrations over time. This was more pronounced Below Spill than At Spill, and generally At Spill stayed within the range of the reference condition throughout the sampling period. This was not the case farther downstream, at Below Spill sites, which were still out of the reference range at the termination of monitoring at all three spill locations. For the Blunn spill, the Below Spill location actually peaked with higher concentrations than the reference range at the very end of the study, while at both the Stillhouse and Williamson spills, the peak at Below Spill sites was still well below the reference concentrations at the end of the study.

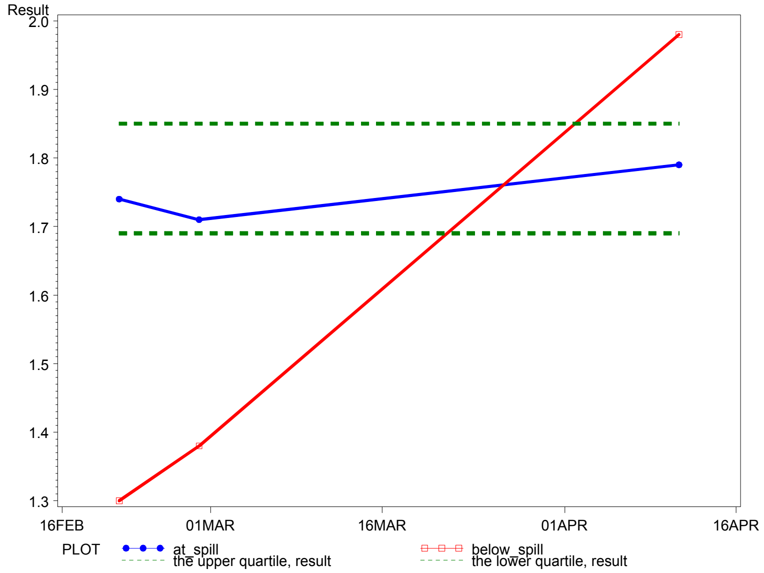

Figure 6a. Control chart for nitrate+nitrite as N at three study sites during Blunn Creek Spill response study, Feb-Apr 2007.

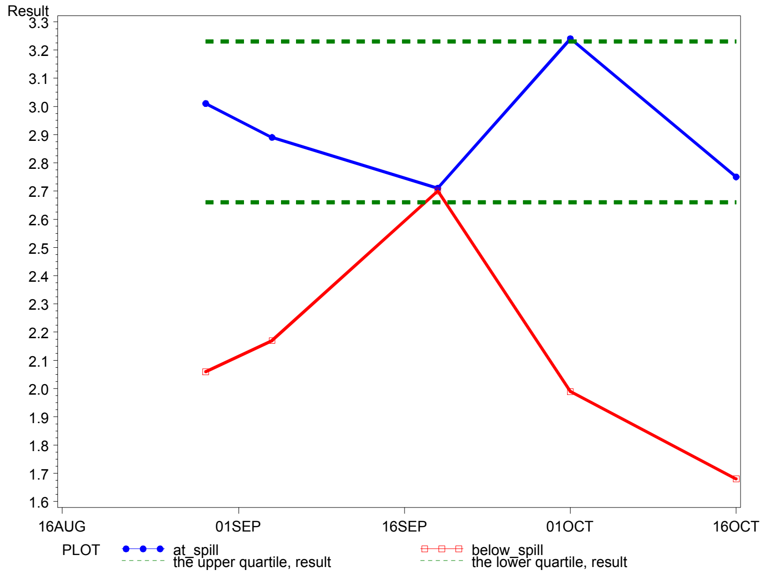

Figure 6b. Control chart for nitrate+nitrite as N at three study sites during Stillhouse Hollow spill response, Aug-Oct 2007.

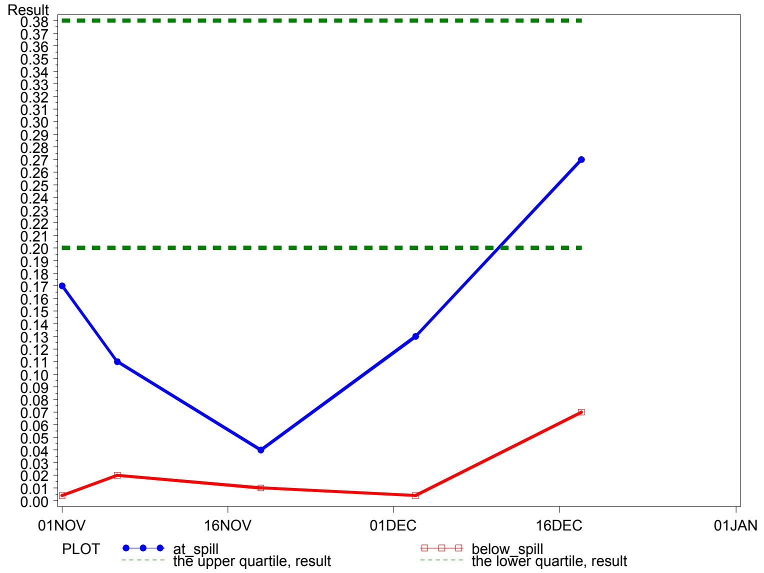

Figure 6c. Control chart for nitrate+nitrite as N at three study sites during Williamson Creek spill response, Nov 2007-Jan 2008.

Ammonia had the opposite, and more consistent, temporal response to spills than nitrate, going from higher concentrations at the two downstream sites immediately following the spill, and moving into the control range by the end of the sampling period (Figs. 7a-c). This was consistent among all three spill events, with Below Spill (in red) generally being almost an order of magnitude higher than the control reference range initially, and coming down to within the control range within about two weeks. The At Spill sites generally started out slightly higher than the reference range and came within it by the end of the study as well.

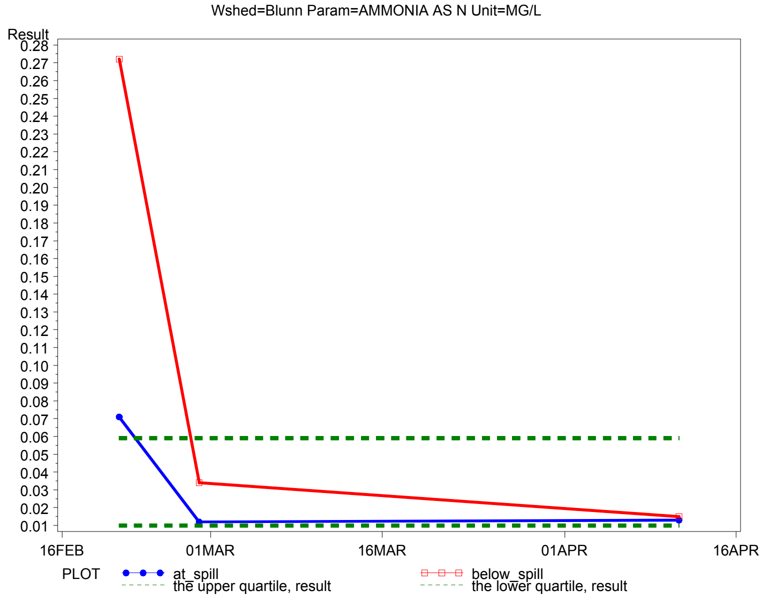

Figure 7a. Control chart for ammonia as N at three study sites during Blunn Creek spill response, Feb-Apr 2007.

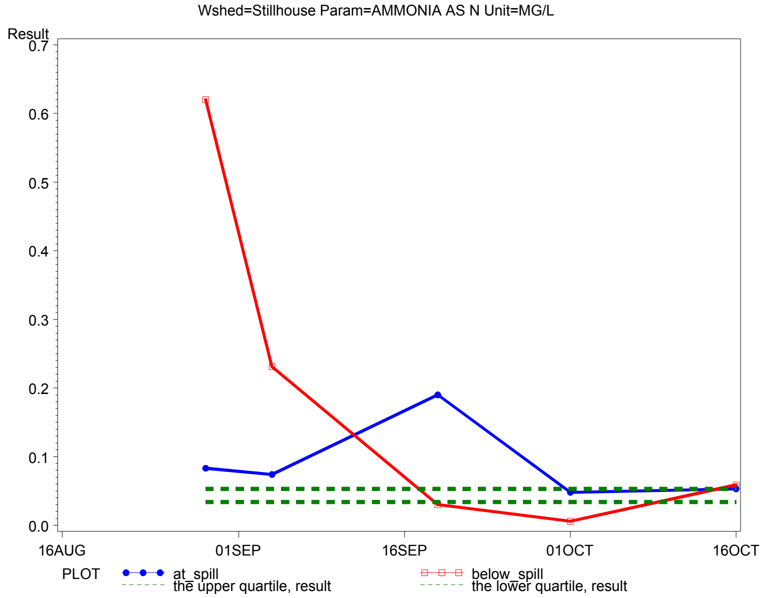

Figure 7b. Control chart for ammonia as N at three study sites during Stillhouse Hollow spill response, Aug-Oct 2007.

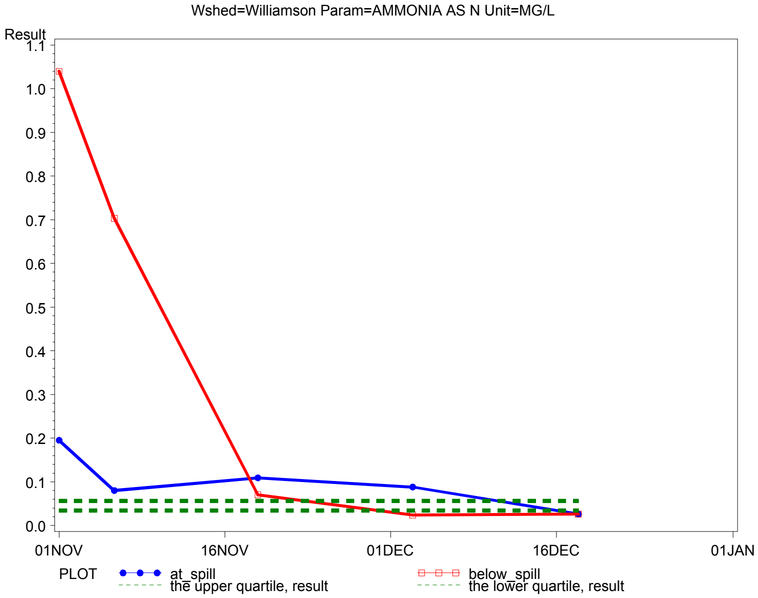

Figure 7c. Control chart for ammonia as N at three study sites during Williamson Creek spill response, Nov 2007-Jan 2008.

Orthophosphorus (OP) was below detection limits at all three reference sites for the duration of each of the monitoring events, and there was generally a spike in OP concentrations at the Below Spill sites (in red), that came back within the control range by the end of the monitoring period (Figs 8a-c). OP concentrations at the At Spill sites did not show increases and generally remained in the control range for the duration of the 7 week study.

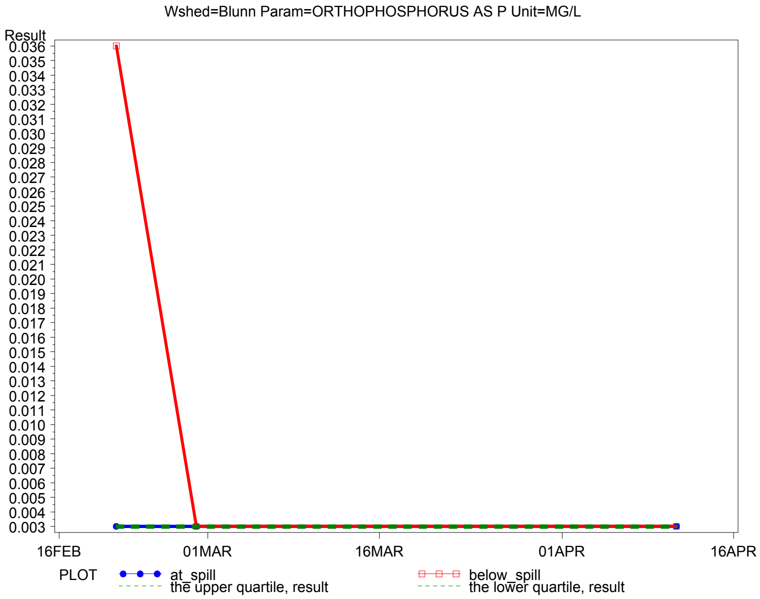

Figure 8a. Control chart for orthophosphorus as P at three study sites during Blunn Creek spill response, Feb-Apr 2007.

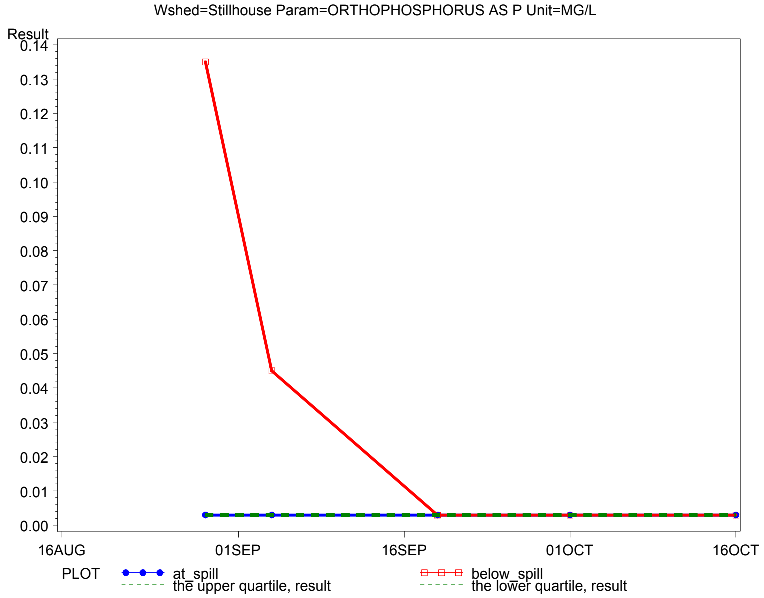

Figure 8b. Control chart for orthophosphorus as P at three study sites during Stillhouse Hollow spill response, Aug-Oct 2007.

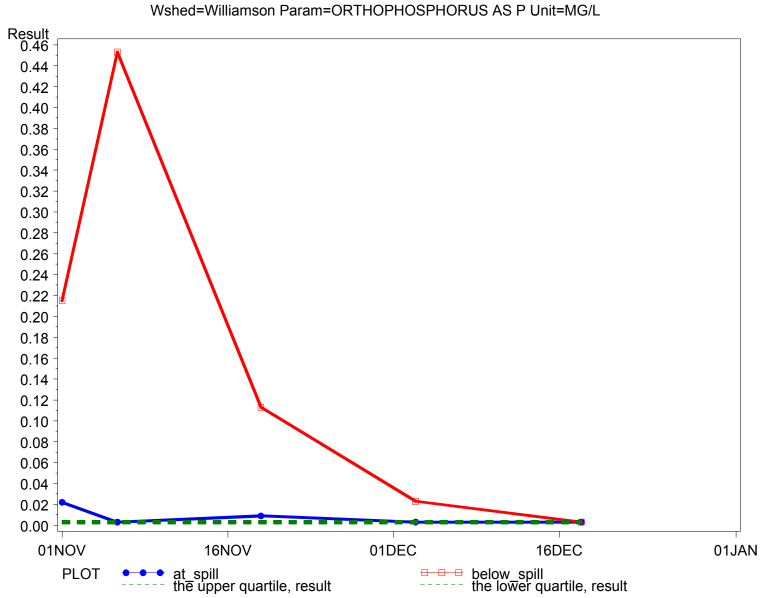

Figure 8c. Control chart for orthophosporus as P at three study sites during Williamson Creek spill response, Nov 2007-Jan 2008.

E. coli bacteria, used as a surrogate for fecal bacteria contamination, showed a somewhat mixed temporal pattern of high concentrations at the beginning of the study period and a return to background levels fairly quickly (Fig 9a-c). The exception was the Stillhouse spill, which increased in *E. coli* concentrations during the first 3 sampling events and then slowly returned to background by the end of the study period (Fig 9b).

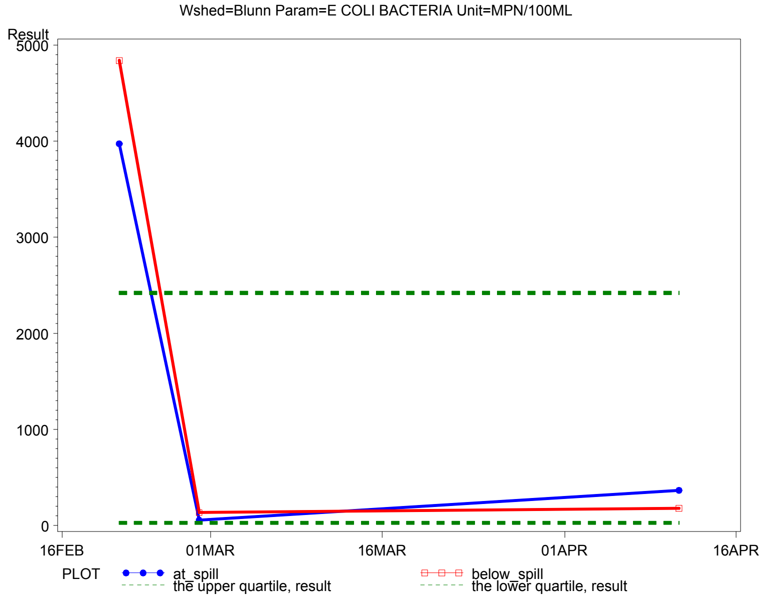

Figure 9a. Control chart for *E. coli* bacteria concentrations at three study sites during Blunn Creek Spill response study, Feb-Apr 2007.

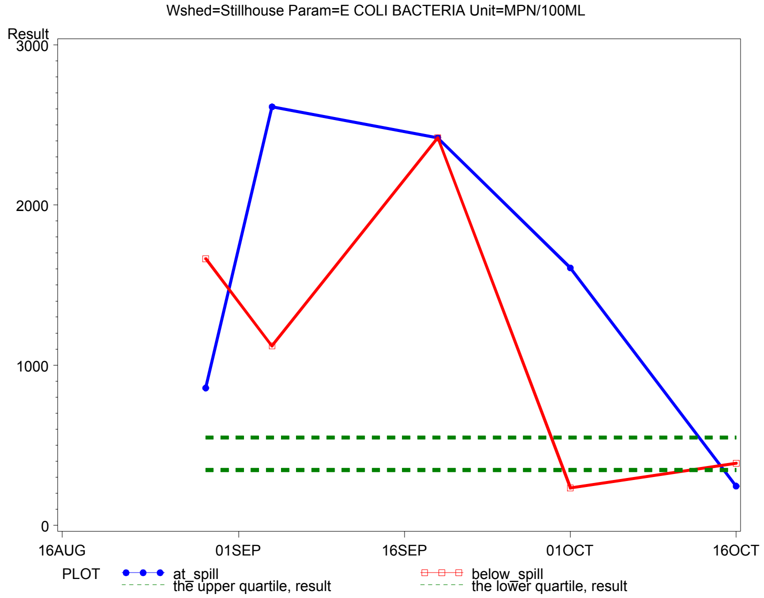

Figure 9b. Control chart for *E. coli* bacteria concentrations at three study sites during Stillhouse Hollow spill response, Aug-Oct 2007.

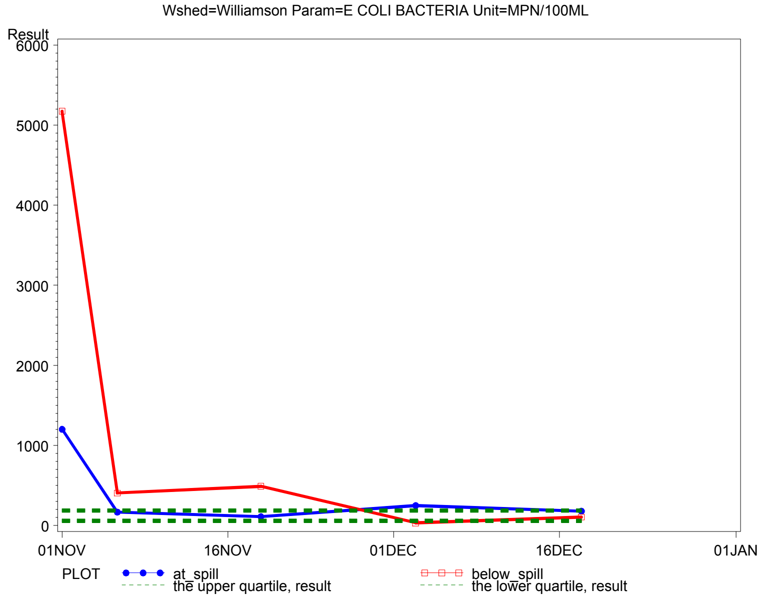

Figure 9c. Control chart for *E. coli* bacteria concentrations at three study sites during Williamson Creek spill response, Nov 2007-Jan 2008.

Nutrient dynamics generally followed predictable patterns, considering the large sewage loads associated with these events. Although it would appear counter-intuitive, nitrate forms increased over time at all three spills. This is probably due to de-nitrification initially caused by the large load of heterotrophic bacteria, with recovery from the pulse sewage release resulting in nitrification as ammonia and other forms of nitrogen are oxidized (Balmforth 1990, Cloern and Oremland 1983). Of note, nitrate concentrations Below Spill did not return to background levels after 7 weeks of sampling, one remaining above reference ranges and two increasing but still below the reference range at the end of the study. Values at the At Spill sites, directly below the spill, showed full recovery by the end of the study. Ammonia increased initially at both downstream sites, more dramatically Below Spill than at Spill, but in all cases, returned to background levels within about 20 days. Orthophosphorus, the most biologically available form of phosphorus, had strong spikes Below Spill initially at all spill events, but had much higher concentrations at the Williamson Creek spill than the other two and remained above background much longer at that spill as well. In all three measured nutrients at all three spills, there was a consistent spatial spill response where concentrations at the Below Spill site, farther away from the spill, showed much higher concentrations and longer response times than the proximate At Spill site. This speaks directly to the concept of nutrient spiraling, and the biotic dynamics that are inherent in this type of large-scale food web alteration (Singer and Battin 2007, Ensign and Doyle 2006). The point of discharge of a resource load such as untreated sewage is just the beginning of the effects on downstream ecosystems and nutrient effects, which likely continue much farther downstream and possibly at larger magnitudes than were observed in this study (Stutter et al. 2010).

E. coli bacteria is one of the primary pollutants of concern in sewage spills, but did not appear to be a long-lived problem in these streams. Initial concentrations in the 1000-8000 MPN/100 mL range are well above background and the Texas single-sample contact recreation criteria (399 MPN/100 mL), but do not reflect the potential loads associated with raw sewage (>50,000

MPN/100 mL). Relatively rapid return to background is likely a factor of dilution and the limited life of these bacteria in the stream environment.

Biology

This study utilized diatom and benthic macroinvertebrate communities to assess temporal and spatial response to sewage spills. Due to the complexity of these data sets, the control chart was selected as the best way to convey the spatial comparisons among the three study sites, and the temporal response over the 7-week study period. In general, univariate metrics were used to quantify community response, and they varied substantially among the different communities and the different metrics used.

The diatom community responded fairly inconsistently to the three sewage spills, both temporally and spatially. Number of diatom taxa, a robust measure of productivity and community health, showed differing responses at the At Spill sites (blue lines), with values initially above (Blunn) and below (Stillhouse) the Above Spill reference site, but with generally increasing/improving values during the study period (Fig 10a-c). In contrast, the Below Spill sites (red lines, Fig 10a-c) all demonstrated increased number of taxa at the initial sampling, compared to the Above Spill reference sites, indicating a stimulation or hysteresis effect (Beisner et al. 2003, Connell 1978). In all three spills, this response returned to background levels by the end of the study period.

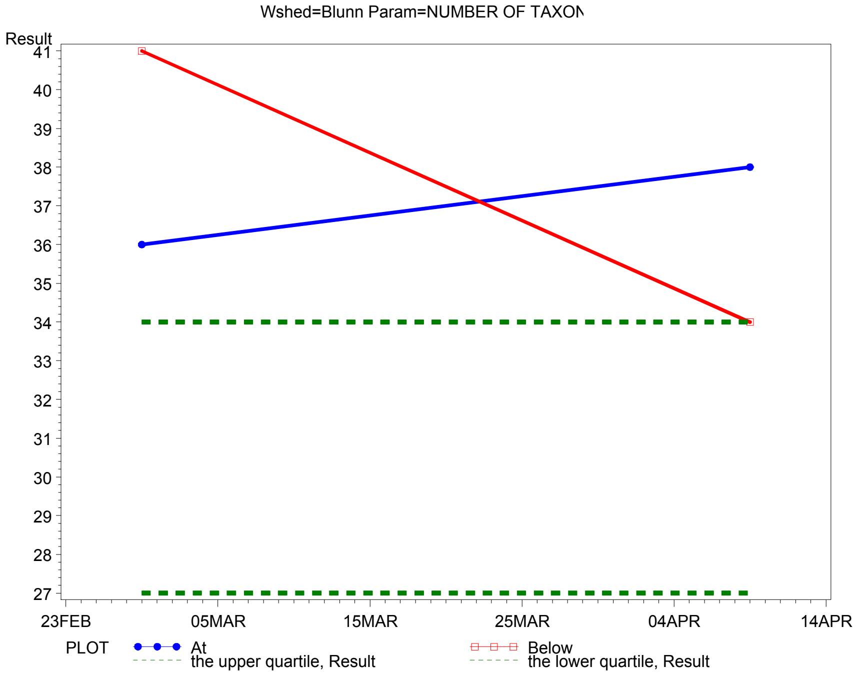

Figure 10a. Control chart for Number of Taxa in the diatom community at three study sites during the Blunn Creek Spill Response study, Feb-Apr 2007.

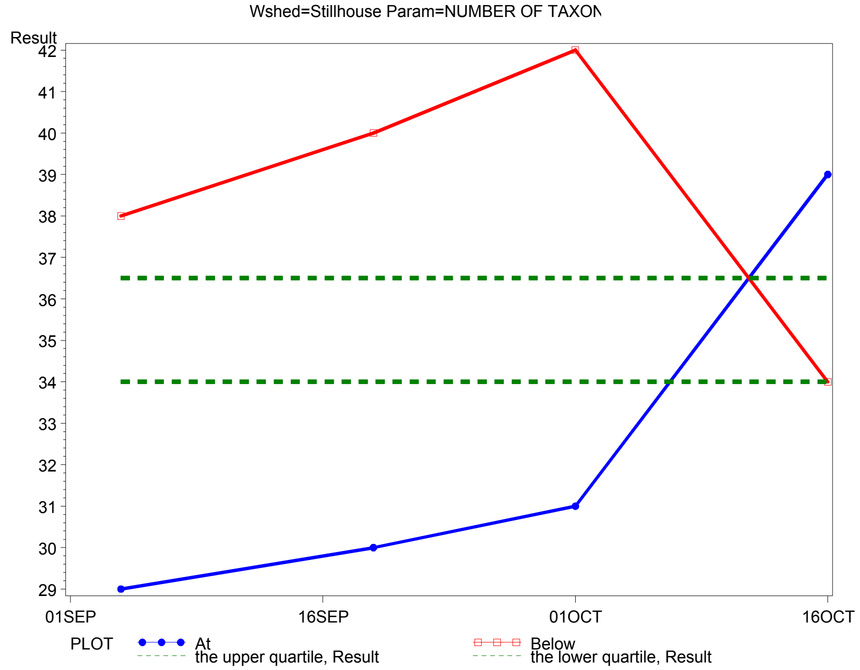

Figure 10b. Control chart for Number of Taxa in the diatom community at three study sites during the Stillhouse Hollow Spill Response study, Aug-Oct 2007.

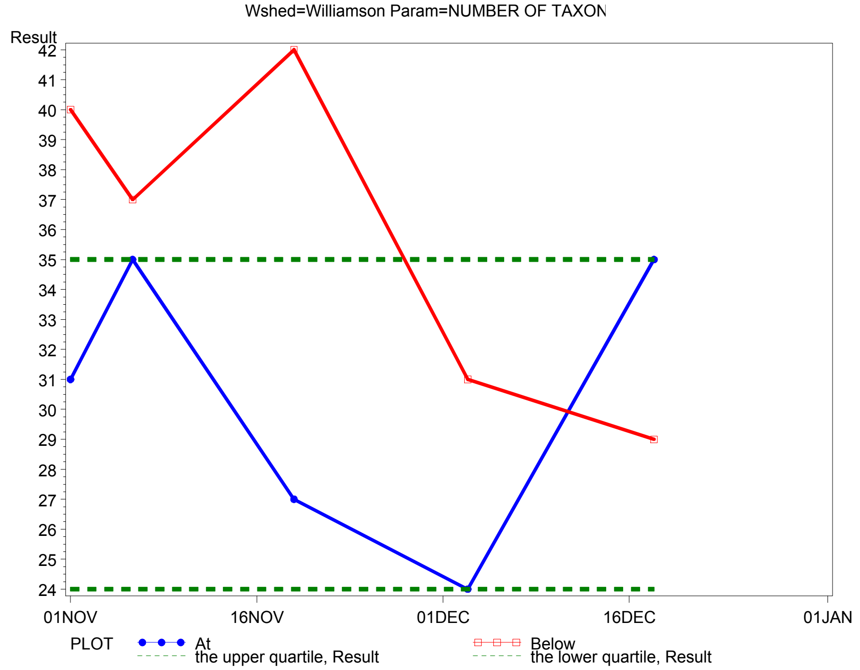

Figure 10c. Control chart for Number of Taxa in the diatom community at three study sites during Williamson Creek Spill Response study, Nov 2007-Jan 2008.

The Diatom Pollution Tolerence Index (PTI, Muscio 2002a) is used to summarize pollution sensitivity across a range of taxa and is generally a good indicator of eutrophication in urban streams (Muscio 2002b). The PTI showed spatial and temporal effects from the sewage inputs, except for the truncated Blunn spill (Fig 11a) which showed no spatial difference at the initial sampling and a divergence away from reference conditions over time at the At Spill and Below Spill sites. At the Stillhouse and Williamson spills, both At Spill and Below Spill sites were degraded substantially below the reference ranges at the initiation of monitoring, and then returned close to reference by the end of the study (Figs 11b, 11c respectively). Spatially, at the Stillhouse and Williamson spills, the proximate At Spill sites were degraded more than the Below Spill site with a much more tolerant community during the initial sampling, but then by the second sampling both At Spill and Below Spill sites had recovered to similar levels.

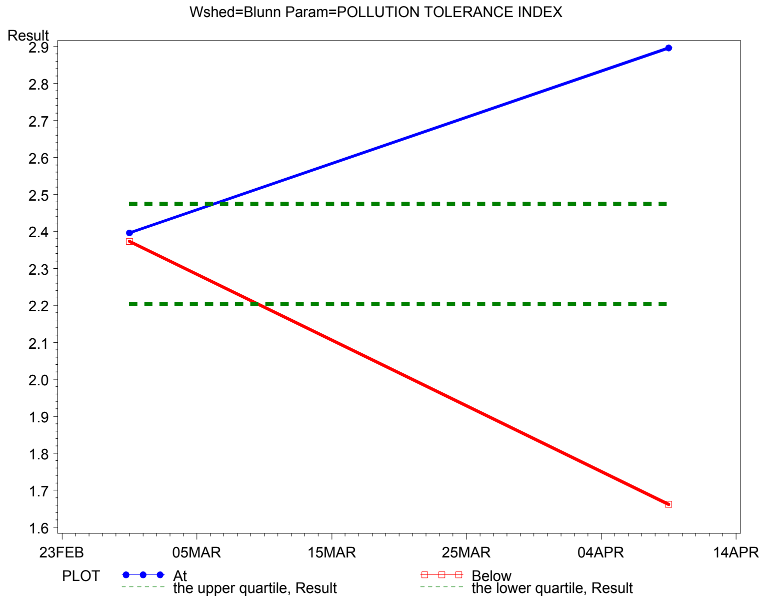

Figure 11a. Control chart for the Diatom Pollution Tolerance Index at three study sites during the Blunn Creek Spill Response study, Feb-Apr 2007.

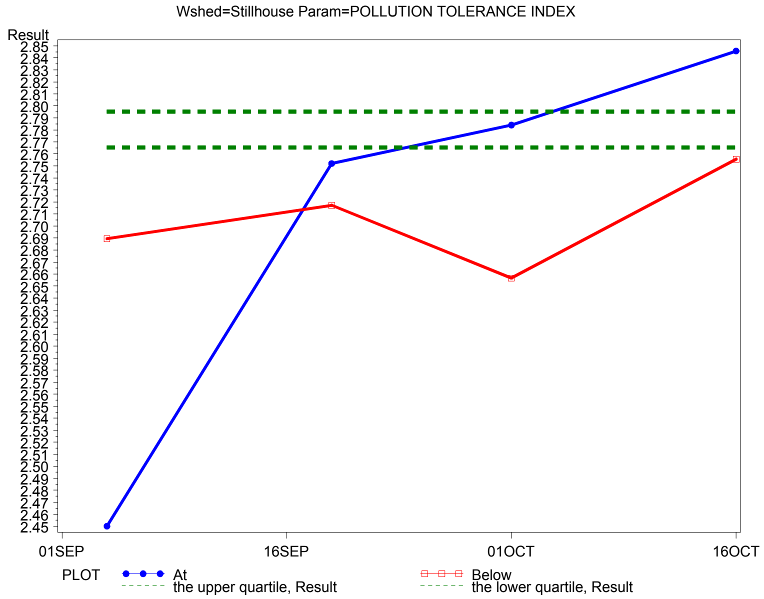

Figure 11b. Control chart for the Diatom Pollution Tolerance Index at three study sites during the Stillhouse Hollow Spill Response study, Aug-Oct 2007.

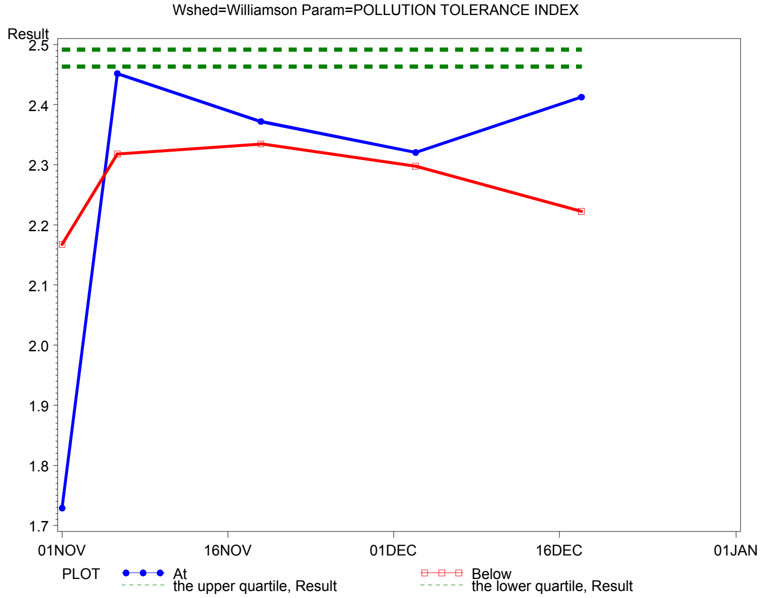

Figure 11c. Control chart for the Diatom Pollution Tolerance Index at three study sites during the Williamson Creek Spill Response study, Nov 2007-Jan 2008.

The two other diatom metrics that were evaluated, *Cymbella* Richness and Percent Motile Taxa, showed no consistent temporal or spatial patterns that were notable in response to the three sewage spills. These metrics are intended to assess bed sediment stability (Percent Motile Taxa) and a group of sensitive taxa (*Cymbella* Richness), although neither metric appeared to exhibit impacts from these sewage spill events in these urban streams.

The benthic macroinvertebrate community metrics (at total of 24) showed a range of clear spatial and temporal responses, but to illuminate general trends, three metrics were chosen that were relatively consistent among the sewage spills studied and represent distinct measures of community health: the Hilsenhoff Biotic Index (HBI), Number (#) of Taxa, and Percent (%) Dominance. The HBI has proven to be a good indicator of organic pollution (Barbour et al. 1999) and showed strong spatial differences, with large differences between the upstream references ranges and both the At Spill and Below Spill locations (Figs 12a-c), particularly at the initiation of the monitoring. There was no clear spatial difference between how the At Spill and Below Spill sites responded to the sewage spills or the recovery trajectory. Over time, only the more urban Blunn spill (Fig 12a) returned to at or even above the reference range, and while the other two spills showed improvement over time, neither Stillhouse (Fig 12b) nor Williamson (Fig 12c) returned to background conditions during the study period.

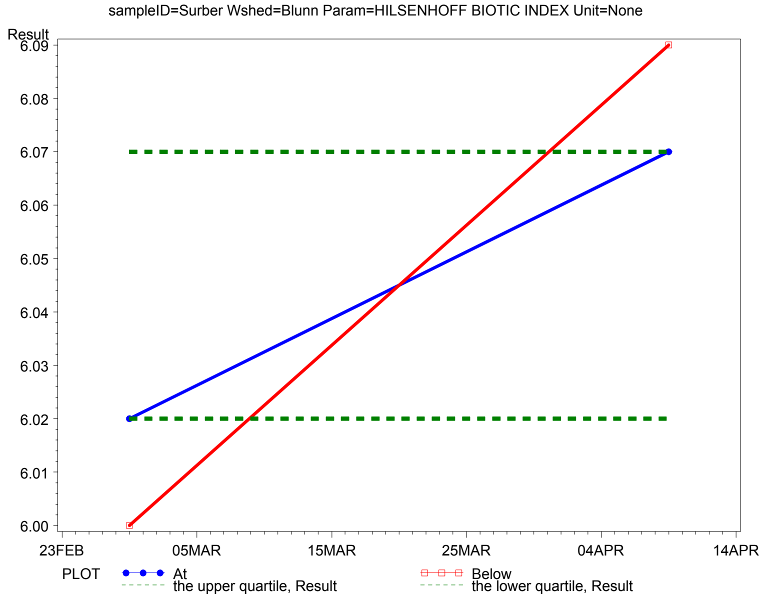

Figure 12a. Control chart for the Hilsenhoff Biotic Index at three study sites during the Blunn Creek Spill Response study, Feb-Apr 2007.

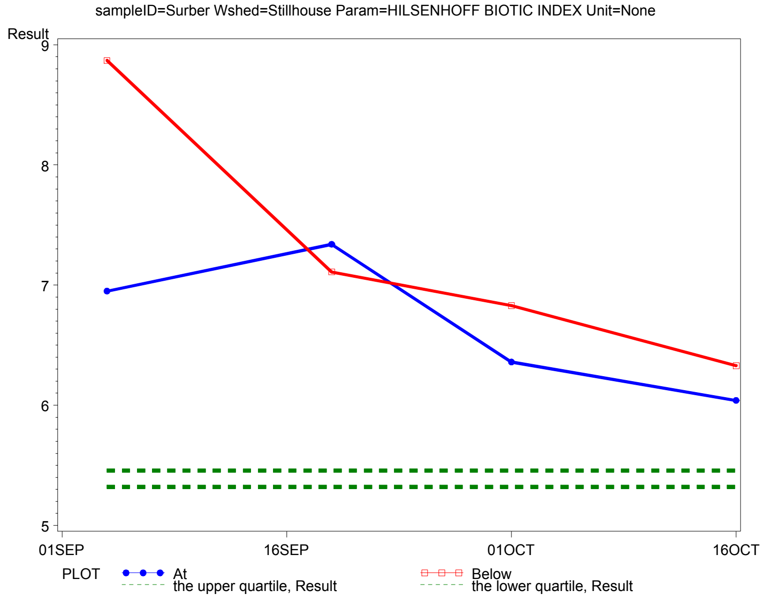

Figure 12b. Control chart for the Hilsenhoff Biotic Index at three study sites during the Stillhouse Hollow Spill Response study, Aug-Oct 2007

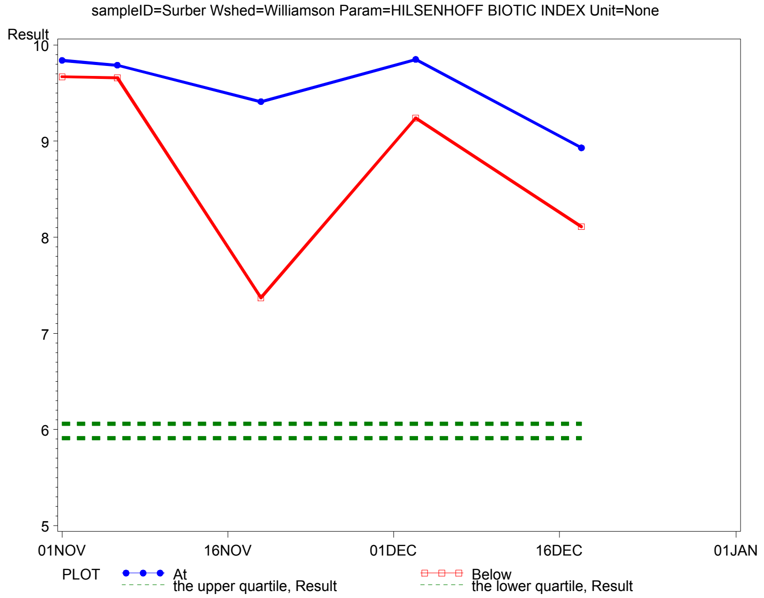

Figure 12c. Control chart for the Hilsenhoff Biotic Index at three study sites during the Williamson Creek Spill Response study, Nov 2007-Jan 2008.

Number of Taxa, a robust measure of community health and resilience, also showed a spatial distinction between the two spill sites and the upstream reference condition (Figs 13a-c), particularly for the Stillhouse and Williamson spills. There was little spatial or temporal difference between the responses at the two spill-affected sites. At Stillhouse and Williamson, while there was substantial recovery during the study period, none of the locations reached background status by the end of the 7-week study period.

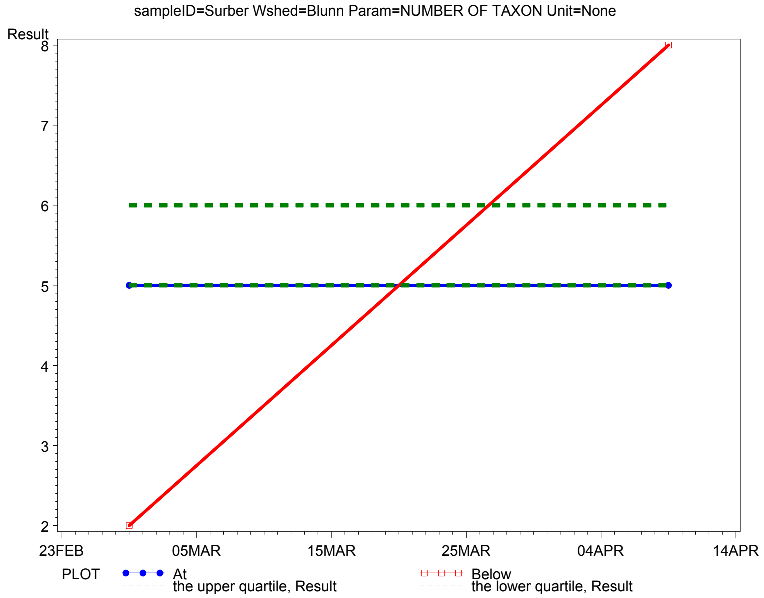

Figure 13a. Control chart for the Number of Taxa at three study sites during the Blunn Creek Spill Response study, Feb-Apr 2007.

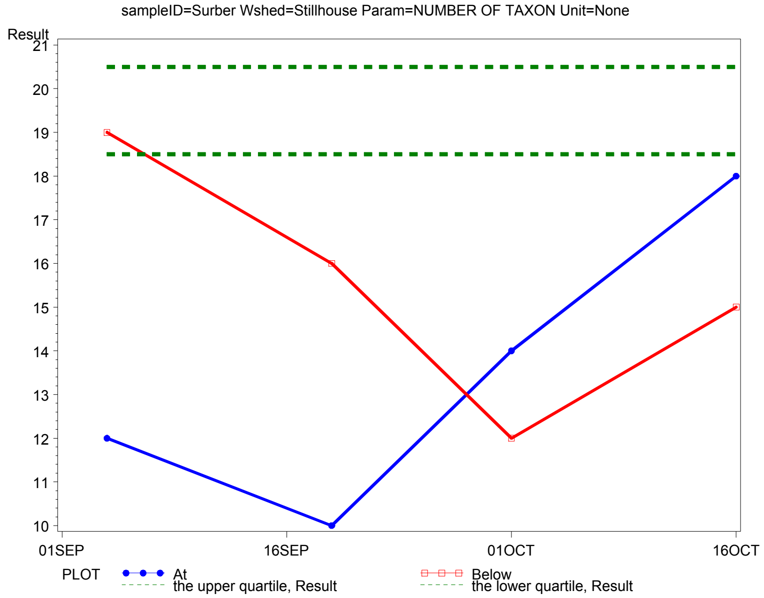

Figure 13b. Control chart for the Number of Taxa at three study sites during the Stillhouse Hollow Spill Response study, Aug-Oct 2007.

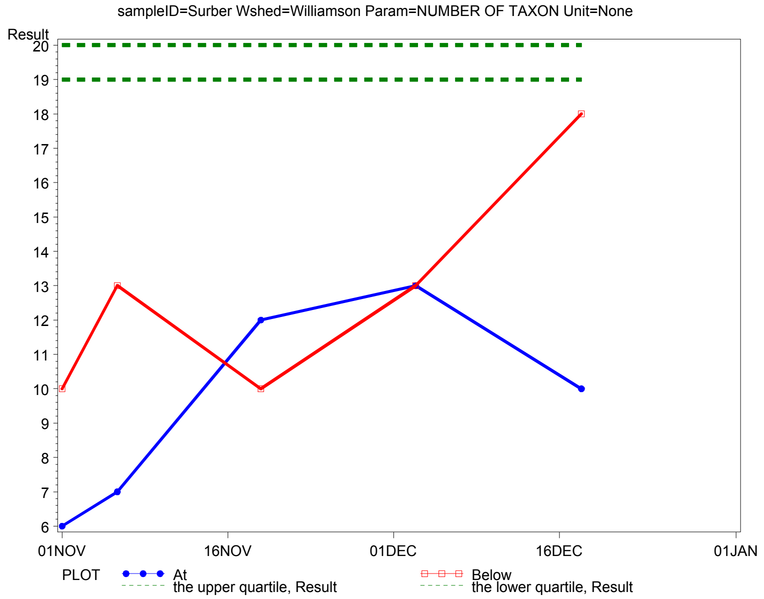

Figure 13c. Control chart for the Number of Taxa at three study sites during the Williamson Creek Spill Response study, Nov 2007-Jan 2008.

Percent Dominance of a single taxon was also a good measure of community recovery, and showed distinct spatial differences between sites (Figs 16a-c). In the Stillhouse and Williamson spill events, the upstream reference condition had much lower percent dominance (20-30%) than the two spill affected sites at the initiation of the study (60-95%), and all three sites showed substantial recovery over time. For this measure, distinct from all others, the Below Spill site appears to have recovered more rapidly and closer to the reference condition than the At Spill site. Full recovery appears to have occurred during the study period at some but not all locations.

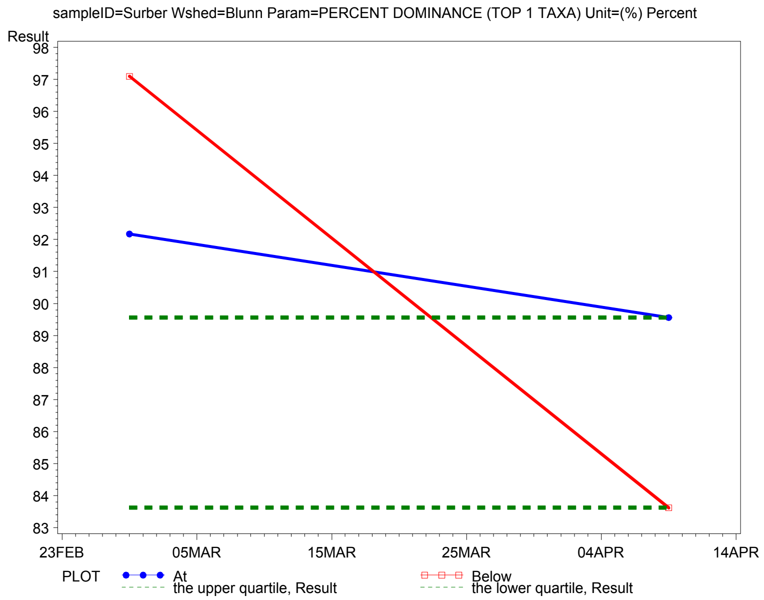

Figure 14a. Control chart for Percent Dominance at three study sites during the Blunn Creek Spill Response study, Feb-Apr 2007.

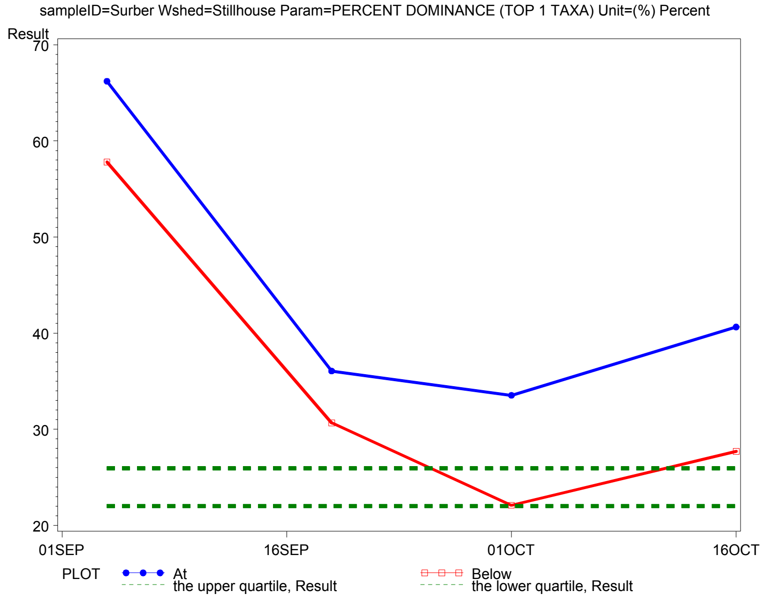

Figure 14b. Control chart for Percent Dominance at three study sites during the Stillhouse Hollow Spill Response study, Aug-Oct 2007.

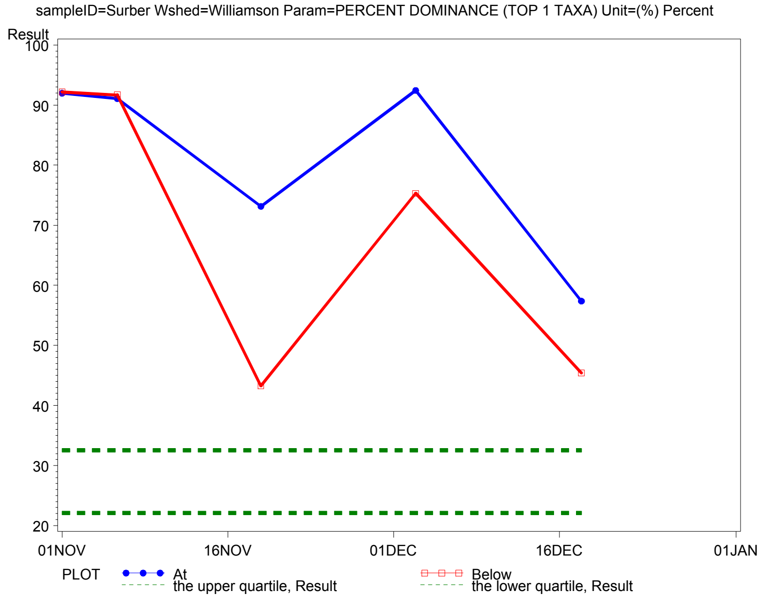

Figure 14c. Control chart for Percent Dominance at three study sites during the Williamson Creek Spill Response study, Nov 2007-Jan 2008.

Dissolved Oxygen

Spatial

Concentrations of dissolved oxygen (DO) over a 24-hour period, considered to be one of the largest threats to aquatic life from sewage, showed distinct spatial patterns at the initiation of the study (Figs 15a-c). In the first 48 hours after the spill had been identified, concentrations of DO at Above Spill reference locations locations were generally very different than either of the two affected spill sites, showing much stronger diel swings (Fig 15a) and on average, lower concentrations (Figs 15 b,c). At the Stillhouse spill (Fig 15b), the At Spill site actually had higher overall oxygen concentrations than either the Above Spill or Below Spill locations, possibly indicating a metabolic stimulation effect, or just differences in habitat aeration among the sites. In the Williamson Creek spill (Fig 15c), concentrations at the two spill affected sites were well below the threshold value of 5 mg/L established by the state to protect aquatic life use for almost the entire 24-hour period. This occurred briefly at the Blunn Spill at the two downstream spill affected sites during the over-night lag (Fig 15a).

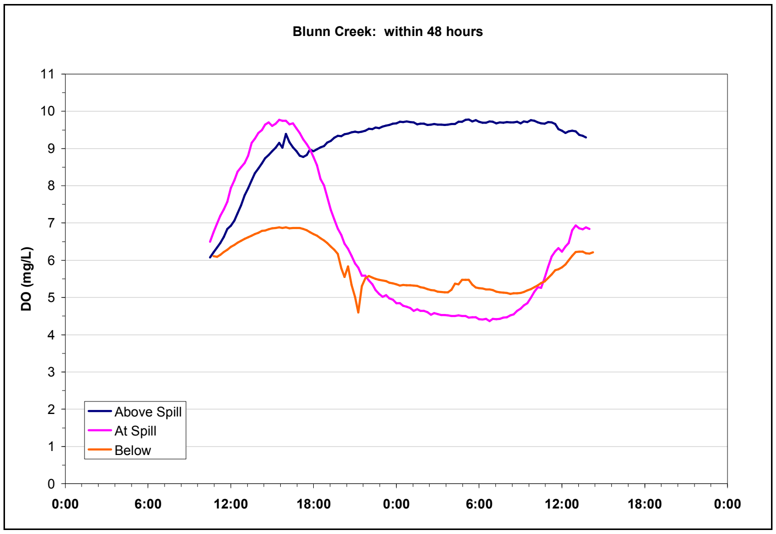

Figure 15a. Dissolved oxygen concentrations on 15 minute intervals for a 24-hour diel period at the 3 discrete study sites, for the Blunn Creek sewage spill. These data were collected within 48-hours of the initiation of the spill investigation.

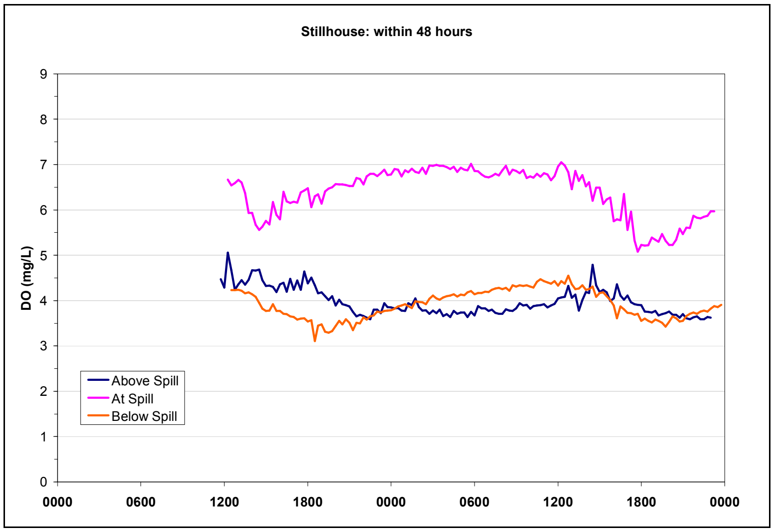

Figure 15b. Dissolved oxygen concentrations on 15 minute intervals for a 24-hour diel period at the 3 discrete study sites, for the Stillhouse Hollow sewage spill. These data were collected within 48-hours of the initiation of the spill investigation.

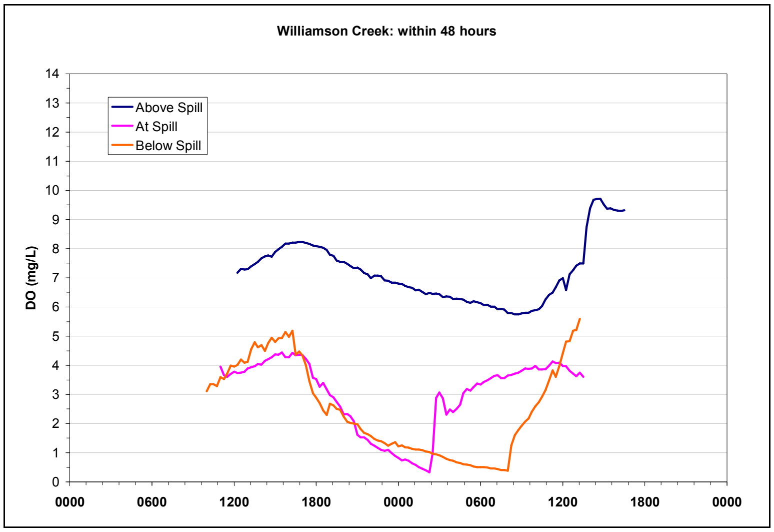

Figure 15c. Dissolved oxygen concentrations on 15 minute intervals for a 24-hour diel period at the 3 discrete study sites, for the Williamson Creek sewage spill. These data were collected within 48-hours of the initiation of the spill investigation.

Temporal

During the entire study period (~7 weeks), average DO values were calculated, based on 24-hour DO measurements in order to evaluate recovery post-spill using the control chart format (Figs 16a-c) to easily compare the spill effected sites (blue and red lines) to the range of the Above Spill reference site (green dotted-lines). In all three spills, recovery to background conditions occurred during the study period, and in the case of both Blunn and Stillhouse, the overall ranges of the upstream reference site was not much different than the ranges of the two spill effected sites (At Spill and Below Spill). In these two cases, there was an increase in average DO concentration over time but spill recovery was more pronounced in the Williamson Creek spill, where values went from about 3 mg/L at both spill effected sites (well below the 5 mg/L aquatic life use average threshold) all the way up to, and even above, the upstream reference range of about 7 mg/L during the 7-week study period.

Figure 16a. Control charts showing average dissolved oxygen concentrations for each measured 24-hour diel period at the 3 discrete study sites, for the Blunn Creek sewage spill.

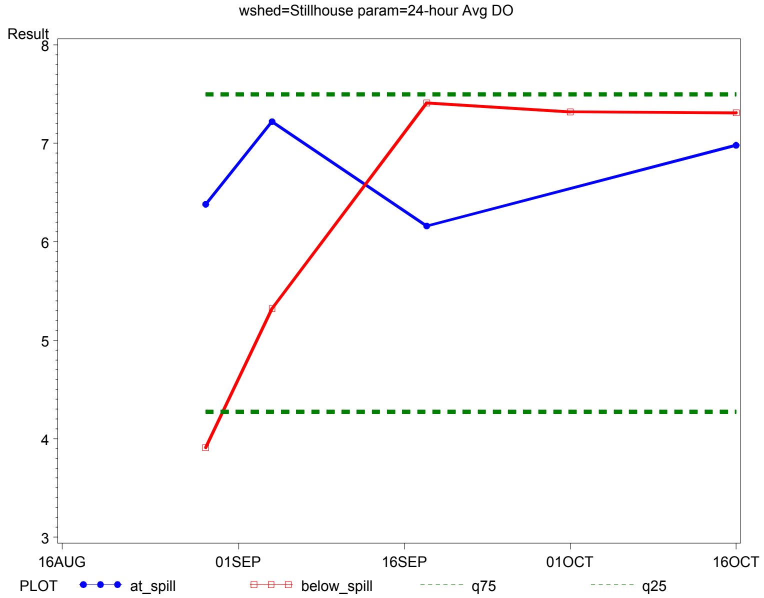

Figure 16b. Control charts showing average dissolved oxygen concentrations for each measured 24-hour diel period at the 3 discrete study sites, for the Stillhouse Hollow sewage spill.

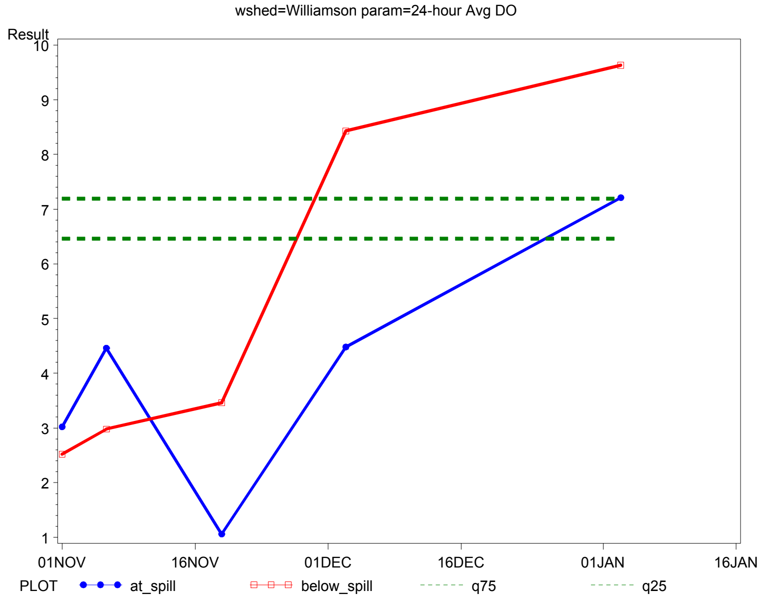

Figure 16c. Control charts showing average dissolved oxygen concentrations for each measured 24-hour diel period at the 3 discrete study sites, for the Williamson Creek sewage spill.

Conclusions

This study documented three different spill types in three different urban streams in Austin, Texas. Each of the events demonstrated different dynamics and had varying antecedent conditions so comparison among them was difficult, but together are a fairly robust assessment of relative impacts to streams in this region. Of note, the Blunn Creek spill, due to limited data and the more urbanized nature of the catchment, provided the least evident stream response by this monitoring method. The Stillhouse and Williamson spills consistently provided similar response patterns even though they have different geomorphic and catchment characteristics and the circumstances of the spills were different. The pulse event at Stillhouse Hollow, in a steep wooded canyon, recovered more quickly even though it generally had a more pollution-intolerant benthic macroinvertebrate community living in the stream (HBI background values of approximately 5, versus 7 for Williamson Creek), possibly due to the longer exposure to the chronic spill on Williamson. The length of time that sewage is introduced to a stream system may be an important variable in both spatial and temporal extent of the negative effects. We originally hypothesized that the volume of the spill would be a good predictor of magnitude and duration of spill effects. Testing this hypothesis was not feasible as all three spills were estimated at a similar total volume, approximately 50,000 gallons (Williamson and Stillhouse at 50,000 gal, Blunn at 40,000 gal). It was also noted in discussions with field sampling and spill response staff that these estimates are not accurate and difficult to verify due to the structure of the wastewater system and the influence of stormwater on these events.

In all three spills events, city staff responded in a similar fashion: stop the sewage from getting in the creek, vacuum/pump out all pooled areas that had evidence of sewage inputs, and flush and remove all solids from the bed of the creek and overland spill areas. This activity inherently affected the results of this study, and although the activities were similar in all three cases, there is no way to assess accurately how each of these responses may have changed study results. This spill clean-up activity is critical in limiting both the short term acute and long term chronic effects that have been documented in this study. Without these remedial actions, the impacts from sanitary sewer overflows in these receiving waters likely would have been much more severe in magnitude and duration.

From a water chemistry perspective, the results of this study were fairly complex, ranging from spikes in ammonia and orthophosphorus immediately following the spill, to drops in nitrate-nitrogen concentrations compared to background levels. It is likely that the effects of the large quantity of dissolved organic inputs from these spill events extends much farther downstream than the boundaries of this study, and for much longer time periods. In heavily urbanized systems, these longer term/larger scale effects may be only low-level “noise” in the Urban Stream Syndrome, but these results help to quantify these specific stressors as they relate to nutrients and the ecosystem shifts in Austin’s streams. Of note, there was an important spatial pattern where the Below Spill site showed higher water quality degradation than the more proximate At Spill site, suggesting that either biotic or abiotic factors are moving, and apparently concentrating these constituents at least one stream reach downstream (20 times bankfull width).

The effects of sewage spills on the communities of invertebrates and algae that live in the study streams was relatively profound, causing large shifts in composition and function, as would be expected. Sensitive taxa were displaced, diversity was reduced, and metabolism was altered. However, probably the most important of these study results was the fact that very few of the measures we used to assess stream health had returned to a background or reference condition within the 7 week study period, and that spatially, effects directly at the spill location (At Spill) and hundreds of feet downstream (Below Spill) were relatively similar. The scale of effect these spills have on stream systems is large, and likely continues spatially and temporally until the next disturbance event occurs, suggesting that urban streams in Austin are in a constant state of adjustment and recovery from just this one stressor. This study did not attempt to assess the effects of undocumented smaller scale sewage overflows that occur only during storm events. These nutrient and solid loads are small in comparison to more acute events, as documented in this study, and benefit from large amounts of dilution and flushing effects. However, they occur much more frequently, and probably generate very similar structural and functional shifts at the receiving-water scale.

Recommendations

- Develop a public education campaign that will enable citizens to recognize and report sewage overflows more quickly and more consistently.
- Working with the WPD Spills team and Austin Water Utility (AWU), develop a sewage spill response protocol and training manual to insure that all clean-up activities are as efficient and consistent as is feasible.
- Using the WPD and AWU databases, identify high-priority areas where spills are likely to occur and result in significant biological impacts, and focus both line-repair and educational activities in these areas.
- Increase the length of clean-up activity (> 1 stream reach) to reflect documented Below Spill effects. Effects may not be visible, but result in significant nutrient and metabolic shifts far below the obvious solids that have been deposited.

- Develop a comprehensive database to track all spill events (both storm and non-storm), including a time and volume measure, and use it as an explanatory variable for Environmental Integrity Index problem scores (Aquatic life use, *E. coli*, nutrients).

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Appendix A. Spatial analysis of water quality and diel in-situ values (24 hour deployed multi-probe) among three study sites (Above Spill, At Spill and Below Spill) at three spill locations (Blunn, Stillhouse, Williamson). Pr>|S| values from Wilcoxon signed-rank test.

		Spill Location	Above Spill vs At Spill	At Spill vs Below Spill	Above Spill vs Below Spill	
Parameter	Unit		Pr>|S|	mean (Abv-At)	Difference	Pr>|S|
24-HOUR AVG CONDUCTIVITY	uS/cm	Blunn	0.7500	-170.86	no diff	1.0000
24-HOUR AVG CONDUCTIVITY	uS/cm	Stillhouse	0.1250	49.04	no diff	0.3125
24-HOUR AVG CONDUCTIVITY	uS/cm	Williamson	0.6250	-8.69	no diff	0.4375
24-HOUR MAX CONDUCTIVITY	uS/cm	Blunn	1.0000	13.67	no diff	1.0000
24-HOUR MAX CONDUCTIVITY	uS/cm	Stillhouse	0.1250	38.50	no diff	0.6250
24-HOUR MAX CONDUCTIVITY	uS/cm	Williamson	0.2500	-16.80	no diff	0.4375
24-HOUR MIN CONDUCTIVITY	uS/cm	Blunn	0.7500	-220.00	no diff	0.7500
24-HOUR MIN CONDUCTIVITY	uS/cm	Stillhouse	0.6250	23.50	no diff	0.3125
24-HOUR MIN CONDUCTIVITY	uS/cm	Williamson	1.0000	-1.20	no diff	0.4375
24-HOUR AVG PH	Standard units	Blunn	1.0000	0.08	no diff	0.5000
24-HOUR AVG PH	Standard units	Stillhouse	0.2500	-0.14	no diff	0.0625
24-HOUR AVG PH	Standard units	Williamson	0.1875	0.06	no diff	0.0625
24-HOUR MAX PH	Standard units	Blunn	1.0000	0.33	no diff	0.2500
24-HOUR MAX PH	Standard units	Stillhouse	0.2500	-0.14	no diff	0.0625
24-HOUR MAX PH	Standard units	Williamson	0.8125	-0.01	no diff	0.0625
24-HOUR MIN PH	Standard units	Blunn	0.7500	-0.03	no diff	0.5000
24-HOUR MIN PH	Standard units	Stillhouse	0.8750	-0.07	no diff	0.3125
24-HOUR MIN PH	Standard units	Williamson	0.4375	0.06	no diff	0.0625
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Blunn	1.0000	-0.08	no diff	0.2500
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.1250	0.19	no diff	0.0625
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Williamson	0.0625	-0.92	At > Abv	0.0625
24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Blunn	0.5000	0.44	no diff	0.2500
24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.8750	-0.03	no diff	1.0000

24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Williamson	0.0625	-0.99	At > Abv	0.0625
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Blunn	0.7500	0.27	no diff	0.2500
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.1250	0.34	no diff	0.0625
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Williamson	0.1250	-1.05	no diff	0.0625
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Blunn	1.0000	0.61	no diff	0.5000
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.30	no diff	0.3125
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.13	Abv > At	0.3125
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Blunn	0.5000	-0.53	no diff	1.0000
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.78	no diff	0.1875
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.12	Abv > At	0.0625
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Blunn	1.0000	0.33	no diff	0.2500
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.05	no diff	0.3125
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.31	Abv > At	0.3125
AMMONIA AS N	MG/L	Blunn	0.2500	-0.01	no diff	0.2500
AMMONIA AS N	MG/L	Stillhouse	0.3125	-0.04	no diff	0.8125
AMMONIA AS N	MG/L	Williamson	0.0625	-0.06	At > Abv	0.6250
CONDUCTIVITY	uS/cm	Blunn	1.0000	24.77	no diff	0.5000
CONDUCTIVITY	uS/cm	Stillhouse	0.0625	49.82	Abv > At	0.6250
CONDUCTIVITY	uS/cm	Williamson	0.3750	-19.45	no diff	0.1250
E COLI BACTERIA	MPN/100ML	Blunn	0.2500	-582.83	no diff	0.7500
E COLI BACTERIA	MPN/100ML	Stillhouse	0.1250	-1108.68	no diff	0.6250
E COLI BACTERIA	MPN/100ML	Williamson	0.4375	-222.60	no diff	0.3125
NITRATE/NITRITE AS N	MG/L	Blunn	0.7500	0.02	no diff	0.5000
NITRATE/NITRITE AS N	MG/L	Stillhouse	1.0000	0.04	no diff	0.0625
NITRATE/NITRITE AS N	MG/L	Williamson	0.0625	0.18	Abv > At	0.0625
ORTHOPHOSPHORUS AS P	MG/L	Blunn		0.00	no diff	1.0000
ORTHOPHOSPHORUS AS P	MG/L	Stillhouse		0.00	no diff	0.5000
ORTHOPHOSPHORUS AS P	MG/L	Williamson	0.5000	-0.01	no diff	0.1250

		Spill	Above Spill vs At Spill			At Spill vs Below Spill			Above Spill vs Below Spill		
Parameter	**Unit**	**Location**	Pr>|S|	mean (Abv-At)	Difference	Pr>|S|	mean (At-Blw)	Difference	Pr>|S|	mean (Abv-Blw)	Difference
24-HOUR AVG CONDUCTIVITY	uS/cm	Blunn	0.7500	-170.86	no diff	1.0000	-23.30	no diff	0.7500	-194.16	no diff
24-HOUR AVG CONDUCTIVITY	uS/cm	Stillhouse	0.1250	49.04	no diff	0.3125	-15.51	no diff	0.2500	29.98	no diff
24-HOUR AVG CONDUCTIVITY	uS/cm	Williamson	0.6250	-8.69	no diff	0.4375	23.35	no diff	1.0000	14.66	no diff
24-HOUR MAX CONDUCTIVITY	uS/cm	Blunn	1.0000	13.67	no diff	1.0000	-32.67	no diff	0.2500	-19.00	no diff
24-HOUR MAX CONDUCTIVITY	uS/cm	Stillhouse	0.1250	38.50	no diff	0.6250	-0.80	no diff	0.2500	37.75	no diff
24-HOUR MAX CONDUCTIVITY	uS/cm	Williamson	0.2500	-16.80	no diff	0.4375	17.20	no diff	1.0000	0.40	no diff
24-HOUR MIN CONDUCTIVITY	uS/cm	Blunn	0.7500	-220.00	no diff	0.7500	135.33	no diff	0.7500	-84.67	no diff
24-HOUR MIN CONDUCTIVITY	uS/cm	Stillhouse	0.6250	23.50	no diff	0.3125	-25.40	no diff	0.8750	-7.75	no diff
24-HOUR MIN CONDUCTIVITY	uS/cm	Williamson	1.0000	-1.20	no diff	0.4375	65.20	no diff	0.6250	64.00	no diff
24-HOUR AVG PH	Standard units	Blunn	1.0000	0.08	no diff	0.5000	-0.10	no diff	1.0000	-0.02	no diff
24-HOUR AVG PH	Standard units	Stillhouse	0.2500	-0.14	no diff	0.0625	0.14	At > Blw	1.0000	-0.02	no diff
24-HOUR AVG PH	Standard units	Williamson	0.1875	0.06	no diff	0.0625	-0.29	Blw > At	0.0625	-0.24	Blw > Abv
24-HOUR MAX PH	Standard units	Blunn	1.0000	0.33	no diff	0.2500	-0.14	no diff	1.0000	0.19	no diff
24-HOUR MAX PH	Standard units	Stillhouse	0.2500	-0.14	no diff	0.0625	0.12	At > Blw	0.7500	-0.03	no diff
24-HOUR MAX PH	Standard units	Williamson	0.8125	-0.01	no diff	0.0625	-0.40	no diff	0.0625	-0.41	Blw > Abv
24-HOUR MIN PH	Standard units	Blunn	0.7500	-0.03	no diff	0.5000	0.04	no diff	1.0000	0.00	no diff
24-HOUR MIN PH	Standard units	Stillhouse	0.8750	-0.07	no diff	0.3125	0.13	no diff	0.6250	0.03	no diff
24-HOUR MIN PH	Standard units	Williamson	0.4375	0.06	no diff	0.0625	-0.24	Blw > At	0.1250	-0.18	no diff
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Blunn	1.0000	-0.08	no diff	0.2500	0.69	no diff	0.5000	0.61	no diff
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.1250	0.19	no diff	0.0625	-0.38	Blw > At	0.1250	-0.18	no diff
24-HOUR AVG WATER TEMPERATURE	Deg. Celsius	Williamson	0.0625	-0.92	At > Abv	0.0625	2.34	At > Blw	0.0625	1.41	Abv > Blw
24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Blunn	0.5000	0.44	no diff	0.2500	0.69	no diff	0.2500	1.13	no diff
24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.8750	-0.03	no diff	1.0000	0.05	no diff	1.0000	0.01	no diff
24-HOUR MAX WATER TEMPERATURE	Deg. Celsius	Williamson	0.0625	-0.99	At > Abv	0.0625	1.53	At > Blw	0.4375	0.54	no diff
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Blunn	0.7500	0.27	no diff	0.2500	1.09	no diff	0.2500	1.36	no diff
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Stillhouse	0.1250	0.34	no diff	0.0625	-0.47	Blw > At	0.6250	-0.12	no diff
24-HOUR MIN WATER TEMPERATURE	Deg. Celsius	Williamson	0.1250	-1.05	no diff	0.0625	3.11	At > Blw	0.0625	2.06	Abv > Blw
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Blunn	1.0000	0.61	no diff	0.5000	-1.35	no diff	0.7500	-0.74	no diff
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.30	no diff	0.3125	0.87	no diff	0.8750	-0.15	no diff
24-HOUR AVG DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.13	Abv > At	0.3125	-1.20	no diff	0.1250	1.93	no diff
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Blunn	0.5000	-0.53	no diff	1.0000	0.09	no diff	0.7500	-0.44	no diff
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.78	no diff	0.1875	1.29	no diff	0.8750	-0.09	no diff
24-HOUR MAX DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.12	Abv > At	0.0625	-3.20	Blw > At	1.0000	-0.08	no diff
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Blunn	1.0000	0.33	no diff	0.2500	-1.40	no diff	0.7500	-1.06	no diff
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Stillhouse	0.6250	-1.05	no diff	0.3125	0.97	no diff	0.6250	0.20	no diff
24-HOUR MIN DISSOLVED OXYGEN	MG/L	Williamson	0.0625	3.31	Abv > At	0.3125	-0.82	no diff	0.1250	2.49	no diff
AMMONIA AS N	MG/L	Blunn	0.2500	-0.01	no diff	0.2500	-0.08	no diff	0.2500	-0.08	no diff
AMMONIA AS N	MG/L	Stillhouse	0.3125	-0.04	no diff	0.8125	-0.10	no diff	0.8125	-0.14	no diff
AMMONIA AS N	MG/L	Williamson	0.0625	-0.06	At > Abv	0.6250	-0.27	no diff	0.3125	-0.33	no diff
CONDUCTIVITY	uS/cm	Blunn	1.0000	24.77	no diff	0.5000	-38.97	no diff	0.2500	-14.20	no diff
CONDUCTIVITY	uS/cm	Stillhouse	0.0625	49.82	Abv > At	0.6250	-17.72	no diff	0.1250	32.10	no diff
CONDUCTIVITY	uS/cm	Williamson	0.3750	-19.45	no diff	0.1250	69.70	no diff	1.0000	69.68	no diff
E COLI BACTERIA	MPN/100ML	Blunn	0.2500	-582.83	no diff	0.7500	-252.63	no diff	0.5000	-835.47	no diff
E COLI BACTERIA	MPN/100ML	Stillhouse	0.1250	-1108.68	no diff	0.6250	383.48	no diff	0.1875	-725.20	no diff
E COLI BACTERIA	MPN/100ML	Williamson	0.4375	-222.60	no diff	0.3125	-859.34	no diff	0.4375	-1081.94	no diff
NITRATE/NITRITE AS N	MG/L	Blunn	0.7500	0.02	no diff	0.5000	0.19	no diff	0.5000	0.21	no diff
NITRATE/NITRITE AS N	MG/L	Stillhouse	1.0000	0.04	no diff	0.0625	0.80	At > Blw	0.0625	0.84	Abv > Blw
NITRATE/NITRITE AS N	MG/L	Williamson	0.0625	0.18	Abv > At	0.0625	0.12	At > Blw	0.0625	0.30	Abv > Blw
ORTHOPHOSPHORUS AS P	MG/L	Blunn		0.00	no diff	1.0000	-0.01	no diff	1.0000	-0.01	no diff
ORTHOPHOSPHORUS AS P	MG/L	Stillhouse		0.00	no diff	0.5000	-0.03	no diff	0.5000	-0.03	no diff
ORTHOPHOSPHORUS AS P	MG/L	Williamson	0.5000	-0.01	no diff	0.1250	-0.15	no diff	0.1250	-0.16	no diff

Appendix B. Evaluation of differences among all benthic macroinvertebrate metrics between Above Spill, At Spill and Below Spill. Pr>|S| values are from Wilcoxon signed-rank test.

			Above Spill vs At Spill			At Spill vs Below Spill			Above Spill vs Below Spill		
Wshed	Param	Unit	Pr>|S|	mean(abv-at)	Diff	Pr>|S|	mean(at-blw)	Diff	Pr>|S|	mean(at-below)	Diff
Blunn	EPT/EPT+CHIRONOMIDAE	Ratio	1.0000	0.00	no diff	1.0000	-0.03	no diff	1.0000	-0.04	no diff
Blunn	HILSENHOFF BIOTIC INDEX	None	0.8750	0.11	no diff	0.5000	0.35	no diff	0.5000	0.50	no diff
Blunn	NUMBER OF DIPTERA TAXA	None	0.2500	1.00	no diff	1.0000	0.00	no diff	0.5000	1.00	no diff
Blunn	NUMBER OF EPHEMEROPTERA TAXA	None	1.0000	-0.25	no diff	1.0000	-0.33	no diff	1.0000	-0.67	no diff
Blunn	NUMBER OF EPT TAXA	None	1.0000	-0.50	no diff		0.00	no diff	1.0000	-0.67	no diff
Blunn	NUMBER OF INTOLERANT TAXA	None	0.5000	0.75	no diff	1.0000	-0.67	no diff		0.00	no diff
Blunn	NUMBER OF NONINSECT TAXA	None	0.5000	0.50	no diff	0.5000	-1.00	no diff	0.5000	-0.67	no diff
Blunn	NUMBER OF ORGANISMS	None	0.8750	2.25	no diff	0.5000	-64.00	no diff	0.7500	-79.33	no diff
Blunn	NUMBER OF TAXON	None	0.2500	0.75	no diff	1.0000	-1.00	no diff	1.0000	-0.33	no diff
Blunn	PERCENT DOMINANCE (TOP 1 TAXA)	(%) Percent	0.8750	-0.81	no diff	1.0000	-9.65	no diff	0.7500	-8.78	no diff
Blunn	PERCENT DOMINANCE (TOP 3 TAXA)	(%) Percent	0.2500	-3.07	no diff	0.5000	-1.75	no diff	0.5000	-5.11	no diff
Blunn	PERCENT OF TOTAL AS CHIRONOMIDAE	(%) Percent	0.8750	4.90	no diff	0.7500	6.70	no diff	0.2500	14.75	no diff
Blunn	PERCENT OF TOTAL AS COLLECTOR/GATHERER	(%) Percent	0.8750	-4.81	no diff	0.7500	-6.86	no diff	0.2500	-14.68	no diff
Blunn	PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	(%) Percent	0.3750	9.38	no diff	0.5000	-13.34	no diff	1.0000	-0.06	no diff
Blunn	PERCENT OF TOTAL AS ELMIDAE	(%) Percent		0.00	no diff		0.00	no diff		0.00	no diff
Blunn	PERCENT OF TOTAL AS EPT	(%) Percent	1.0000	-0.13	no diff	1.0000	-2.44	no diff	1.0000	-3.52	no diff
Blunn	PERCENT OF TOTAL AS FILTERERS	(%) Percent	0.8750	5.86	no diff	0.7500	7.30	no diff	0.2500	15.84	no diff
Blunn	PERCENT OF TOTAL AS GRAZERS (PI AND SC)	(%) Percent	0.7500	-0.30	no diff	1.0000	-1.43	no diff	1.0000	-3.23	no diff
Blunn	PERCENT OF TOTAL AS PREDATOR	(%) Percent	0.8750	7.75	no diff	0.7500	7.54	no diff	0.2500	18.65	no diff
Blunn	PERCENT OF TOTAL AS TOLERANT ORGANISMS	(%) Percent	0.5000	4.27	no diff	0.5000	1.68	no diff	0.5000	7.37	no diff
Blunn	PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	(%) Percent	1.0000	-25.00	no diff	1.0000	33.33	no diff		0.00	no diff
Blunn	RATIO OF INTOLERANT TO TOLERANT ORGANISMS	(%) Percent	1.0000	0.01	no diff	1.0000	0.00	no diff	1.0000	0.01	no diff
Blunn	TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	None	0.2500	2.50	no diff	0.2500	-3.33	no diff	0.7500	-1.33	no diff
Blunn	TCEQ QUANTITATIVE AQUATIC LIFE USE SCORE	None	0.5000	-1.00	no diff		0.00	no diff	0.5000	-1.33	no diff
Stillhouse	EPT/EPT+CHIRONOMIDAE	Ratio	0.3125	0.31	no diff	0.4375	-0.04	no diff	0.3125	0.27	no diff
Stillhouse	HILSENHOFF BIOTIC INDEX	None	0.0313	-1.75	At > Abv	0.4375	-0.37	no diff	0.0625	-2.11	Blw > Abv
Stillhouse	NUMBER OF DIPTERA TAXA	None	0.7500	0.50	no diff	0.2500	0.67	no diff	0.1250	1.17	no diff
Stillhouse	NUMBER OF EPHEMEROPTERA TAXA	None	1.0000	0.00	no diff	0.5000	0.33	no diff	0.5000	0.33	no diff
Stillhouse	NUMBER OF EPT TAXA	None	0.1250	1.33	no diff	0.1250	0.83	no diff	0.0625	2.17	Abv > Blw
Stillhouse	NUMBER OF INTOLERANT TAXA	None	0.0313	2.50	Abv > At	0.2500	0.67	no diff	0.0313	3.17	Abv > Blw
Stillhouse	NUMBER OF NONINSECT TAXA	None	0.2813	1.17	no diff	0.1875	-2.17	no diff	0.5000	-1.00	no diff
Stillhouse	NUMBER OF ORGANISMS	None	0.0625	-125.50	At > Abv	0.3125	38.33	no diff	0.3125	-87.17	no diff
Stillhouse	NUMBER OF TAXON	None	0.0625	4.50	Abv > At	0.8438	-0.83	no diff	0.0313	3.67	Abv > Blw
Stillhouse	PERCENT DOMINANCE (TOP 1 TAXA)	(%) Percent	0.1563	-12.34	no diff	1.0000	-1.20	no diff	0.0313	-13.54	Blw > Abv
Stillhouse	PERCENT DOMINANCE (TOP 3 TAXA)	(%) Percent	0.8438	-0.14	no diff	0.3125	-8.51	no diff	0.0625	-8.65	Blw > Abv
Stillhouse	PERCENT OF TOTAL AS CHIRONOMIDAE	(%) Percent	0.0625	-40.77	At > Abv	1.0000	0.61	no diff	0.0625	-40.16	Blw > Abv
Stillhouse	PERCENT OF TOTAL AS COLLECTOR/GATHERER	(%) Percent	0.6875	2.15	no diff	0.3125	-7.66	no diff	0.4375	-5.51	no diff
Stillhouse	PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	(%) Percent	0.3125	-11.93	no diff	0.3125	7.21	no diff	0.6875	-4.72	no diff
Stillhouse	PERCENT OF TOTAL AS ELMIDAE	(%) Percent	0.2500	0.81	no diff	0.2500	-0.26	no diff	0.8750	0.55	no diff
Stillhouse	PERCENT OF TOTAL AS EPT	(%) Percent	0.6875	10.81	no diff	0.6250	-4.11	no diff	0.8125	6.70	no diff
Stillhouse	PERCENT OF TOTAL AS FILTERERS	(%) Percent	0.0313	-42.91	At > Abv	0.4375	4.17	no diff	0.0313	-38.75	Blw > Abv
Stillhouse	PERCENT OF TOTAL AS GRAZERS (PI AND SC)	(%) Percent	0.1563	21.01	no diff	0.1875	-10.06	no diff	0.6875	10.94	no diff
Stillhouse	PERCENT OF TOTAL AS PREDATOR	(%) Percent	0.2188	-31.43	no diff	0.3125	7.21	no diff	0.4375	-24.22	no diff
Stillhouse	PERCENT OF TOTAL AS TOLERANT ORGANISMS	(%) Percent	0.1563	-22.89	no diff	0.6875	-5.19	no diff	0.2188	-28.08	no diff
Stillhouse	PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	(%) Percent	0.0625	-70.00	At > Abv	1.0000	11.82	no diff	0.1250	-58.18	no diff
Stillhouse	RATIO OF INTOLERANT TO TOLERANT ORGANISMS	(%) Percent	0.0313	0.64	Abv > At	1.0000	-0.06	no diff	0.0313	0.58	Abv > Blw
Stillhouse	TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	None	0.0313	6.83	Abv > At	0.1250	-2.00	no diff	0.0625	4.83	Abv > Blw
Stillhouse	TCEQ QUANTITATIVE AQUATIC LIFE USE SCORE	None	0.0313	6.67	Abv > At	0.3125	-3.33	no diff	0.4375	3.33	no diff
Williamson	EPT/EPT+CHIRONOMIDAE	Ratio	0.0156	0.53	Abv > At	0.7500	0.01	no diff	0.0156	0.54	Abv > Blw
Williamson	HILSENHOFF BIOTIC INDEX	None	0.0156	-2.84	At > Abv	0.2813	0.08	no diff	0.0156	-2.76	Blw > Abv
Williamson	NUMBER OF DIPTERA TAXA	None	0.5000	-0.29	no diff	0.2500	-0.86	no diff	0.2500	-1.14	no diff
Williamson	NUMBER OF EPHEMEROPTERA TAXA	None	0.0313	1.43	Abv > At	1.0000	-0.14	no diff	0.0313	1.29	Abv > Blw
Williamson	NUMBER OF EPT TAXA	None	0.0156	3.57	Abv > At	1.0000	-0.29	no diff	0.0156	3.29	Abv > Blw
Williamson	NUMBER OF INTOLERANT TAXA	None	0.2500	1.14	no diff	0.2500	-0.86	no diff	0.6250	0.29	no diff
Williamson	NUMBER OF NONINSECT TAXA	None	0.0156	2.57	Abv > At	0.6250	-0.43	no diff	0.0625	2.14	Abv > Blw
Williamson	NUMBER OF ORGANISMS	None	1.0000	-45.43	no diff	0.3750	-58.14	no diff	0.0781	-103.57	Blw > Abv
Williamson	NUMBER OF TAXON	None	0.0156	8.00	Abv > At	0.6875	-0.86	no diff	0.0313	7.14	Abv > Blw
Williamson	PERCENT DOMINANCE (TOP 1 TAXA)	(%) Percent	0.0156	-47.65	At > Abv	0.5781	-1.44	no diff	0.0156	-49.09	Blw > Abv
Williamson	PERCENT DOMINANCE (TOP 3 TAXA)	(%) Percent	0.0156	-28.86	At > Abv	0.5781	-1.45	no diff	0.0156	-30.32	Blw > Abv
Williamson	PERCENT OF TOTAL AS CHIRONOMIDAE	(%) Percent	0.0313	-57.86	At > Abv	0.9375	-5.23	no diff	0.0156	-63.09	Blw > Abv
Williamson	PERCENT OF TOTAL AS COLLECTOR/GATHERER	(%) Percent	0.0313	11.17	Abv > At	0.2969	-5.55	no diff	0.6875	5.62	no diff
Williamson	PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	(%) Percent	0.0469	-26.75	At > Abv	0.4688	-5.83	no diff	0.0156	-32.58	Blw > Abv
Williamson	PERCENT OF TOTAL AS ELMIDAE	(%) Percent	0.5625	-4.43	no diff	0.4688	4.46	no diff	0.8125	0.03	no diff
Williamson	PERCENT OF TOTAL AS EPT	(%) Percent	0.0156	12.28	Abv > At	0.7500	0.88	no diff	0.0156	13.16	Abv > Blw
Williamson	PERCENT OF TOTAL AS FILTERERS	(%) Percent	0.0469	-51.00	At > Abv	0.2188	-12.11	no diff	0.0156	-63.11	Blw > Abv
Williamson	PERCENT OF TOTAL AS GRAZERS (PI AND SC)	(%) Percent	0.5781	7.35	no diff	0.0156	14.30	At > Blw	0.0313	21.65	Abv > Blw
Williamson	PERCENT OF TOTAL AS PREDATOR	(%) Percent	0.1094	-26.46	no diff	0.6875	-6.97	no diff	0.0469	-33.43	Blw > Abv
Williamson	PERCENT OF TOTAL AS TOLERANT ORGANISMS	(%) Percent	0.0313	-72.59	At > Abv	0.2969	-2.46	no diff	0.0156	-75.05	Blw > Abv
Williamson	PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	(%) Percent	0.0625	45.18	Abv > At		0.00	no diff	0.0625	45.18	Abv > Blw
Williamson	RATIO OF INTOLERANT TO TOLERANT ORGANISMS	(%) Percent	0.0156	0.11	Abv > At	0.2188	-0.05	no diff	0.4688	0.06	no diff
Williamson	TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	None	0.0156	8.43	Abv > At	0.7656	0.86	no diff	0.0313	9.29	Abv > Blw
Williamson	TCEQ QUANTITATIVE AQUATIC LIFE USE SCORE	None	0.0313	7.43	Abv > At	1.0000	1.14	no diff	0.0313	8.57	Abv > Blw