



BULL CREEK WATER QUALITY UPDATE 2001

By Ellen Geismar
Environmental Scientist
Environmental Resources Management Division

ABSTRACT

Since 1993, the City of Austin has conducted various monitoring programs in Bull Creek in response to concerns about rapid development and degradation of water quality entering Lake Austin, the primary City drinking water reservoir. Studies have been completed concerning protection of the Jollyville salamander and regulation of traffic and development in this and other Water Supply Suburban watersheds. A long-term USGS gaging station has provided historical water quality and flow data for Bull Creek near the mouth at Loop 360. In addition, TNRCC and LCRA have conducted several intensive surveys in the creek. General conclusions of previous reporting from the various agencies involved indicated that Bull Creek water quality was excellent overall; however, development pressures were discernable from episodic non-point source pollution events associated with residential construction in the lower reaches of the creek.

This update report examines data available from the COA sampling program conducted in Bull Creek and tributaries since the completion of the Jollyville salamander monitoring study in 1998. The data analysis indicates that water chemistry and aquatic life at undeveloped or rural sites (such as Franklin Tract and Hanks Tract) recover quickly from natural environmental stressors such as drought and subsequent scouring floods. These two sites also apparently assimilated higher nitrate concentrations from the first spate following drought conditions and had no reported algae blooms during the following wet winter (2000-2001). By contrast, the other more developed subwatershed sites had shown both nutrient spikes during wet periods immediately following drought and nuisance algae blooms the following winter. The undeveloped sites are also consistently lower in dissolved metals and conductivity. Spring discharges also result in consistently higher nitrate concentrations in Tributaries 5 and 6 during baseflow conditions potentially related to spring-shed development intensity. Construction in the West Bull Creek watershed and in the Balcones Canyonland Preserve (BCP) may also be the cause of elevated total suspended solids concentrations and turbidity in baseflow measurements from West Bull Creek at Jester Boulevard and from the Tributary 5 site upstream of the Gardens of Bull Creek flood detention control structure. Although macroinvertebrate populations appear to be similar, subtle differences appear between sites, including a loss of sensitive species at sites with nutrient enrichment and sediment accumulation. In general, monitoring of this watershed has continued to track degradation of water quality with development despite current levels of regulation and identified areas where water quality remediation efforts may be needed.

INTRODUCTION

Bull Creek is the largest watershed (20,254 acres) draining directly into Lake Austin. It can have a substantial influence on the City of Austin's (COA) drinking water supply during winter months when releases from Lake Travis are curtailed (up to 37 percent of Lake Austin inflow on a monthly basis). Bull Creek is unique in Northwest Austin because of the numerous springs that discharge from the Edwards and Glen Rose Limestone formations along its tributary canyons. In addition to their aesthetic and recreational value, Bull Creek canyons are ecologically significant due to the perennial flows from seeps and springs, which provide habitat year round for a large number of aquatic organisms (COA, 1987). Additionally, many critical environmental features related to Northern Edwards aquifer karst geology, such as springs, seeps, rimrocks, caves, and sinkholes, are located throughout the Bull Creek watershed.

Terrestrial and aquatic environmentally sensitive areas are abundant in the Bull Creek watershed. The sensitive areas include habitat for rare endangered species, the Golden-Cheeked Warbler (*Dendroica*

chrysoparia) and the Black-Capped Vireo (*Vireo atricapillus*), high-quality woodlands, and high-quality aquatic habitat (COA, 1987). Bull Creek includes many sites where the Jollyville Plateau salamander, *Eurycea tonkawae* (Chippindale, Price, Wiens, and Hillis) is located, a Category 2 species of concern identified by USFWS under the Endangered Species Act.

Slopes in the Bull Creek area generally range from 5 to 15 percent; some slopes exceed 15 percent. The soils in the Bull Creek watershed consist of Tarrant, Brackett, Volente, and Austin-Eddy. Tarrant soils consist of very shallow, rocky and clayey materials overlying hard limestone on nearly level to sloping land. These soils are the predominant type in the Jollyville Plateau area. Brackett soils consist of shallow gravelly, loamy materials, which often overlie interbedded hard and soft limestone on gently undulating to steeply sloping landscapes. Brackett soils are the primary association of steep canyons and broken ridges in the Bull Creek watershed. Volente complex soils are deep silty clay with low to moderate expansivity. Austin-Eddy soils consist of moderately deep clayey and loamy materials, overlying chalky limestone on nearly level to rolling landscapes (COA, 1997). Major tributaries to Bull Creek include West Bull Creek and a series of unnamed tributaries (COA designates with tributary numbers for reference), contributing flow to the mainstem at each confluence.

DATA SOURCES/AVAILABILITY

Water quality evaluations of Bull Creek have been published by TNRCC (1982), LCRA (1998), and COA (1993, 1999). Long-term flow and water quality data (1976-present) are only available for one site on Bull Creek, at Loop 360, through the U.S. Geological Survey (USGS), (USGS, 1999). In addition, the COA maintains and has maintained monitoring in the watershed since 1993, samples some wells and springs in the area, and provides cooperative funding for the USGS to obtain additional samples.

The Jollyville Plateau Water Quality and Salamander Assessment (COA, 2002) report contains water quality information from September 1996 through 1998. Regular water quality sampling of Bull Creek by COA was suspended during the Jollyville salamander project. Monitoring and water quality sampling by COA resumed in June 1999 and is conducted quarterly. Sites are visited in February, May, August, and November. In addition, linear habitat monitoring of areas of Tributaries 5 and 6 upstream of the Gardens of Bull Creek flood control structure is performed annually. Periodic Jollyville salamander surveys are performed by COA staff with assistance from TPWD and UT. This report covers water quality and biological data collected by COA from June 1999 through the year 2000 from routine surface water quality monitoring. Data from the USGS and COA monitoring programs were also used in a compilation of information about the Water Supply Suburban Watersheds reported to the Austin City Council in response to recent concerns about development pressures in this area of Austin (COA, 1999).

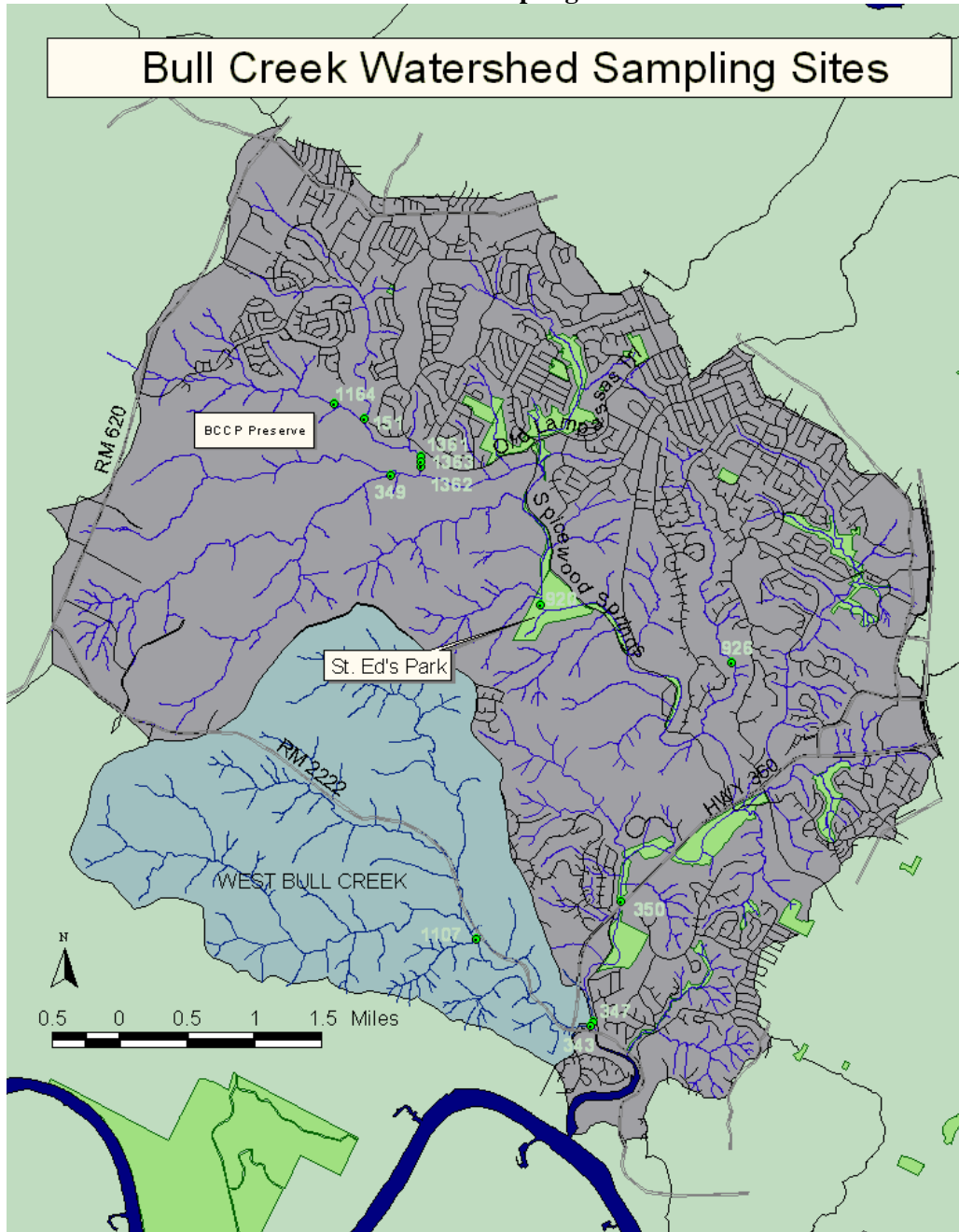
MONITORING SITES

Four water quality sites on the mainstem of Bull Creek were monitored during this period, including Bull Creek at the mouth upstream of the confluence with West Bull Creek, Bull Creek at Loop 360 (1st Crossing), Bull Creek in St. Edwards Park off of Spicewood Springs Rd., and Bull Creek above Tributary 7 on the Franklin Tract of the BCP. Canyon tributary sites monitored during this period included Tributary 5 (aka Hanks Tract) and Tributary 6 (aka collapsed bridge). Both of these sites are located on the Hanks Tract of the BCP property. The canyon tributaries and the main stem Franklin Tract site sampled are Jollyville Plateau salamander habitat. A sampling site was added on Tributary 5, downstream of the confluence of Tributaries 5 and 6 and upstream of the construction of the City of Austin regional flood control facility known as the Gardens of Bull Creek pond, to determine impacts the structure may have on upstream sediment deposition, habitat and water quality. This site is also a Jollyville Plateau salamander (*E. tonkawae*) habitat.

Two sites on the largest tributary, West Bull Creek, were also monitored concurrently. One site is located at the mouth of West Bull where it joins with Bull Creek before flowing into Lake Austin. A second site

is located along RR 2222, upstream of Loop 360, near Jester Blvd. The Bull, West Bull, and canyon tributary sites were monitored quarterly during baseflow conditions for field parameters and conventional chemical water quality constituents. Benthic macroinvertebrates were collected semiannually at these sites during this period. Locations of the monitoring sites are shown in Figure 1.

Figure 1
Bull Creek Sampling Sites



SITE DESCRIPTIONS

The following information is provided to identify sampling sites and characterize the subwatersheds draining into them. Land-use breakdown was provided by 1995 maps from COA's Planning and Transportation Department. The impervious cover is provided through GIS coverages created by ASI, Inc., for CAPCO and the COA from aerial photography flown in 1997. Appendix 1 includes complete impervious cover and land-use estimates by site.

Canyon Tributaries

Tributary 6 (FSDB#151)

The site monitored on Tributary 6 is located on the COA's BCP property known as the Hanks Tract and is upstream of the confluence with Tributary 5. This tributary flows through the Spicewood at Balcones, Balcones Village, Spicewood Estates, and Estates of Brentwood subdivisions. The Balcones Country Club golf course is located in the upper two-thirds of the drainage area. Although the majority of the tributary is surrounded by residential neighborhoods, the BCP land buffers the lower third. Impervious cover is greater than 16.2 percent, and therefore the site is classified as developed, or urban (16.2 percent impervious cover). This site is located in known Jollyville Plateau salamander habitat.

Tributary 5 (FSDB#1164)

Tributary 5 is also located on BCP property on Hanks Tract. Tributary 5 (Field Sampling Database (FSDB) #1164) flows through the Canyon Creek residential neighborhood, although a wide undeveloped area is present that provides a buffer between the neighborhood and the creek. Because impervious cover is estimated at less than 4.8, the site is classified as undeveloped or rural. The monitoring site is upstream of the confluence with Tributary 6 in known Jollyville Plateau salamander habitat. A second monitoring site in Tributary 5 monitored is described below.

Tributary 5 Riffle 6 (FSDB #1361)

Site 1361 was added in March 2000 as a regular monitoring site after construction of the Gardens of Bull Creek flood control structure in the creek channel of Tributary 5. The potential for sedimentation and the resulting effects of periodic inundation upstream of the structure will be monitored with water quality and biological assessments. The site is located in Jollyville Plateau salamander habitat. This site is directly downstream of the confluence of Tributaries 5 and 6 and is a relatively equal mix of rural and urban land uses, with 11.4 percent impervious cover.

Bull Creek above Tributary 7 (FSDB#349)

Bull Creek above Tributary 7 is a mainstem site located in the BCP property known as the Franklin Tract. Although this is a mainstem site, it has all the characteristics of the canyon sites; a small, shady, spring-fed, low-flow canyon with a large riparian buffer. For comparisons in this report it was included in the canyon sites. The site monitored is upstream of the confluence with Tributary 7, downstream of the confluence with Tributary 8 and directly adjacent to the discharge of Pit Spring. Impervious cover is less than 15 percent and the site is classified as rural (undeveloped, 3.3 percent impervious cover). This location is in documented Jollyville Plateau salamander habitat.

Main Stem Sites

Bull Creek near the mouth (FSDB#347)

This mainstem site is located upstream of the confluence of Bull Creek with Lake Austin, upstream of RR2222 and upstream of the confluence with West Bull Creek. The site is the most downstream location monitored on Bull Creek. The site consists of bedrock, boulder, and cobble substrate with intermittent in-stream vegetation. Substantial riparian buffer area is present in the immediate area. This site normally has the highest flows and represents the cumulative impacts on water quality from the entire watershed, as it

is the most downstream site. The mouth site, with overall 14 percent impervious cover, is considered to be at the more developed end of the rural watersheds.

Bull Creek at Loop 360 (FSDB#350)

This site is located downstream of the first Loop 360 crossing in the mainstem of Bull Creek and consists mainly of large areas of bedrock substrate with gullies and cobble deposits. The site does not support a large in-stream vegetated area. The banks of Bull Creek in this area are constructed cement skirts from the Loop 360 roadway and some flat, previously disturbed vegetated areas. Directly upstream of Loop 360 is greenbelt. As mentioned, this site has a long-term USGS station and is classified as urban with 18.8 percent impervious cover in the subwatershed.

Bull Creek at St. Edwards Park (FSDB#920)

The site is located in the mainstem of Bull Creek in St. Edwards Park on Spicewood Springs Road, west of Loop 360 in Northwest Austin. The monitoring site is one fourth of a mile upstream of the park dam and one fourth of a mile downstream of the low water crossing on Spicewood Springs Road. The site includes a large braided riffle with islands, bedrock and cobble deposits. A large amount of the filamentous algae *Chara* is usually present, mixed with other aquatic vegetation (*Nitella*, *Justicia americana*) at the site. The park consists of a large riparian buffer with native and non-native trees and shrubs, and fields of wildflowers. This area surrounding the stream supports large populations of butterflies, dragonflies and damselflies in addition to a large population of fish and amphibians in the creek. Low impervious cover estimates of 3.3% in the subwatershed contribute to the rural characteristics of this site.

West Bull Creek Sites

West Bull is a large tributary joining with Bull Creek near the mouth. The influence of this creek is not observed at the majority of mainstem sampling sites, since it joins Bull Creek so close to the confluence with Lake Austin (Figure 1). However, West Bull contributes a substantial volume of water to Lake Austin (up to 3 percent of the inflow during some months when Lake Travis releases are curtailed) and may impact Lake Austin water quality under these conditions. A considerable amount of development is currently ongoing in the West Bull watershed that could potentially change the character of the creek in the next few years.

West Bull at the mouth (FSDB#343)

The confluence of West Bull Creek with Bull Creek is located downstream of site #347, in a narrow bedrock channel with consistent flow. The site is sampled about 50 feet upstream of the confluence. Although the site has a low 5.5 percent impervious cover estimate in the subwatershed, it is directly downstream of the Loop 360 and RR 2222 intersection and receives runoff from both roadways.

West Bull at Jester Blvd. (FSDB#1107)

This site is upstream of the creek crossing of Loop 360 and RR 2222, directly adjacent to Jester Blvd on RR 2222. A pooled area is located near this sample site; however, biological samples are taken at downstream riffles where flow is apparent. The riparian buffer is large locally, with many large trees and dense groundcover vegetation. Impervious cover estimates are 4.8 percent, which would categorize this site as rural; however, the considerable amount of construction ongoing upstream in this watershed may temporarily be an overriding influence.

RESULTS

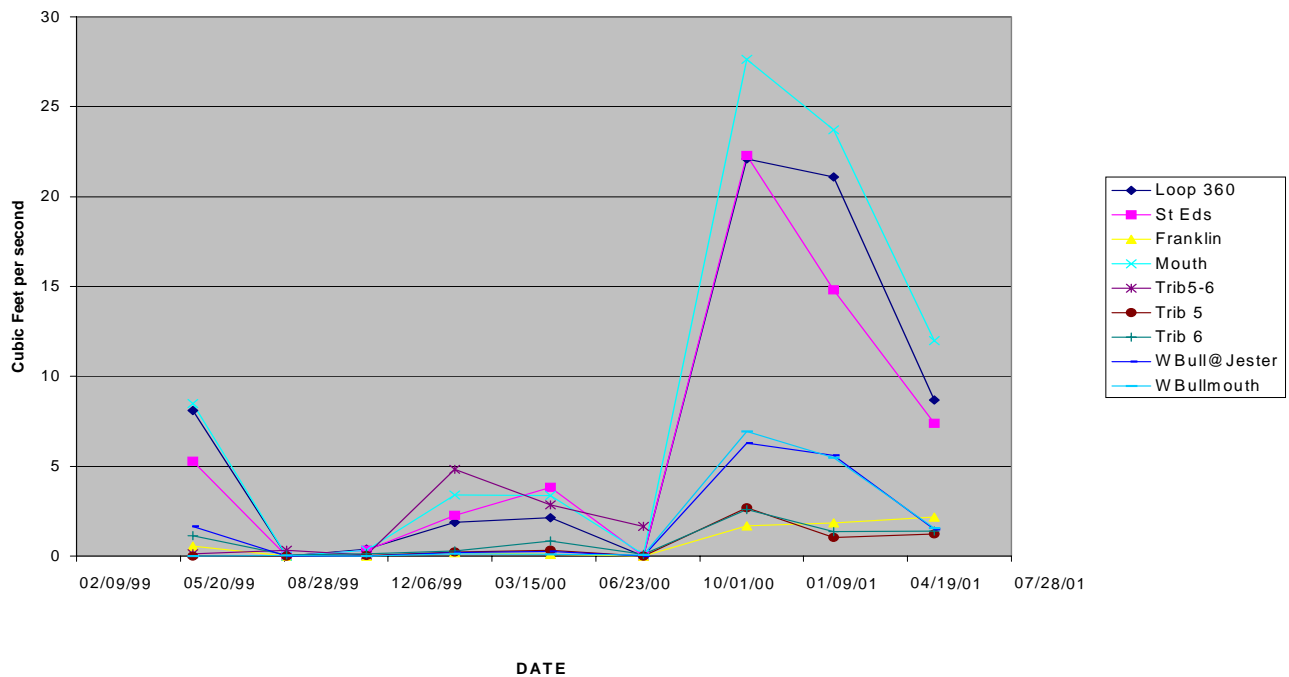
Flows

The Bull Creek watershed surficial geology consists of outcrops of the Edwards-Walnut, the Glen Rose and Quaternary system formations. Edwards-Walnut and Glen Rose springs are the major sources of baseflow in the Bull Creek canyons (COA, 1987). Perennial springs are located throughout the watershed, and usually flow is perennial in most of the mainstem of Bull Creek as well as in West Bull Creek. However, due to unusually extreme drought conditions in the year 2000, several sites were dry during summer and fall water quality collections.

Flow was measured quarterly during water quality collections, representing low as well as high baseflow periods (Figure 2). Based on field observations from June 1999 through November 2000, Tributary 6 (#151), Tributary 5 Riffle 6 (#1361), and the Bull Creek Mouth site had maintained at least minimal flows during August 2000, whereas other Bull Creek mainstem and tributary sites have experienced no-flow conditions. Lower flowing sites near the headwaters located on Franklin (#349) and Hanks Tracts (#1164) of the BCP have seasonally intermittent flows and routinely are dry during summer months. Mainstem flow losses, as indicated by dry conditions at St. Edward's Park and stagnant pool conditions at Loop 360, may be due to subterranean flow during hot summer droughts.

As is illustrated in Figure 2, the three mainstem sites typically have large flow volumes, while the remainder of sites average lower flows. In the lower mainstem flows ranged from 0 (during drought conditions) to 28 cfs. Flows in the upper mainstem, Franklin Tract site, and in the canyon head tributaries ranged from 0 to 2.8 cfs. The two West Bull sites have flows ranging from 0 (Jester Blvd.-during drought conditions) to a maximum of approximately 6 cfs.

Figure 2
Flow Regime Bull Creek June 1999- May 2001



Physiochemical Parameters

Between June 1999 and December 2000, seven separate water collections were made. Parameters evaluated included dissolved oxygen (DO), conductivity (COND), pH, nitrate/nitrite as N (NO3), ammonia as N (NH3), total Kjeldhal nitrogen (TKN), total suspended solids (TSS), turbidity, volatile suspended solids (VSS), chemical oxygen demand (COD), total phosphorus (TP), ortho-phosphorus (OP), and chloride and sulfate. Inorganic ions including calcium, magnesium, potassium, and sodium were analyzed at all sites that are known salamander habitat. All samples were collected during baseflow conditions, as defined by no antecedent rainfall greater than 0.1 inch, for at least 24 hours prior to sampling.

Dissolved Oxygen, Temperature, and Chemical Oxygen Demand

Dissolved oxygen (DO) is an important parameter used in evaluating the health of aquatic ecosystems, and the amount of oxygen that can dissolve in water (saturation) is inversely proportional to the temperature. Oxygen is a requirement for metabolism of aerobic organisms and also influences the equilibrium and rates of many inorganic chemical reactions. If dissolved oxygen levels fall below 5.0 mg/l, high quality aquatic life is often put under stress. If levels remain below 1–2 mg/L for even short periods, large fish kills can occur (State of Kentucky, 2001). Only once during this period was the dissolved oxygen measured below 5.0 mg/L in Bull Creek. During the August 2000 drought, many sites sampled were dry or stagnant and water temperatures were elevated. These conditions led to low dissolved oxygen levels at several sampling locations. Bull Creek at Loop 360 and the mouth sites on Bull and West Bull measured less than 5 mg/L dissolved oxygen during this summer sampling. Oxygen levels recovered with subsequent rainfall, increased flows and cooler weather.

Chemical oxygen demand (COD) data can assist in determining the amount of organic pollution in water and in explaining why dissolved oxygen levels are depressed. This parameter does not measure the amount of a particular substance; rather, it measures the effect of a combination of substances with potential to deplete dissolved oxygen. Organic materials (natural organic substances, insecticides, herbicides, and wastewaters) can enter streams in rainfall runoff and increase the oxygen demand in natural water bodies. Table 1 illustrates the levels of chemical oxygen demand measured in Bull Creek. A large increase in COD can indicate a wastewater leak or a variety of organic contamination problems (KY, 2001). Large spikes were not measured during the sampling period. In the Austin area, urban sites commonly have higher COD levels during periods of low flow and rural sites tend to stay at or below the detection limits for this parameter. This can be seen in the results from the more rural Hanks Tract and Franklin Tract sites in Table 1.

**Table 1.
Chemical Oxygen Demand in Bull Creek June 1999-November 2000**

Site Name	Category	Jun-99	Aug-99	Nov-99	Feb-00	May-00	Aug-00	Nov-00
Bull Creek @ Loop 360 #350	Urban	8.7	10.9	<5	5	<5	10.6	6.3
Bull Creek @ St. Eds #920	Urban	7.5	na	<5	<5	<5	na	8.7
Bull Creek Franklin #349	Rural	<5	na	na	7	<5	na	<5
Bull Creek Mouth #347	Urban	9.8	12.8	<5	7	<5	10.2	<5
Tributary 5 Riffle 6 #1361	Urban*	na	na	na	<5	<5	<5	7.5
Tributary 5 Hanks #152	Rural	<5	na	<5	<5	<5	na	<5
Tributary 6 #151	Urban	5	<5	<5	10	<5	<5	10.2
West Bull Jester #1107	Rural+	6	na	na	<5	<5	na	<5
West Bull Mouth #343	Rural+	na	<5	<5	7	6.3	<5	7.5

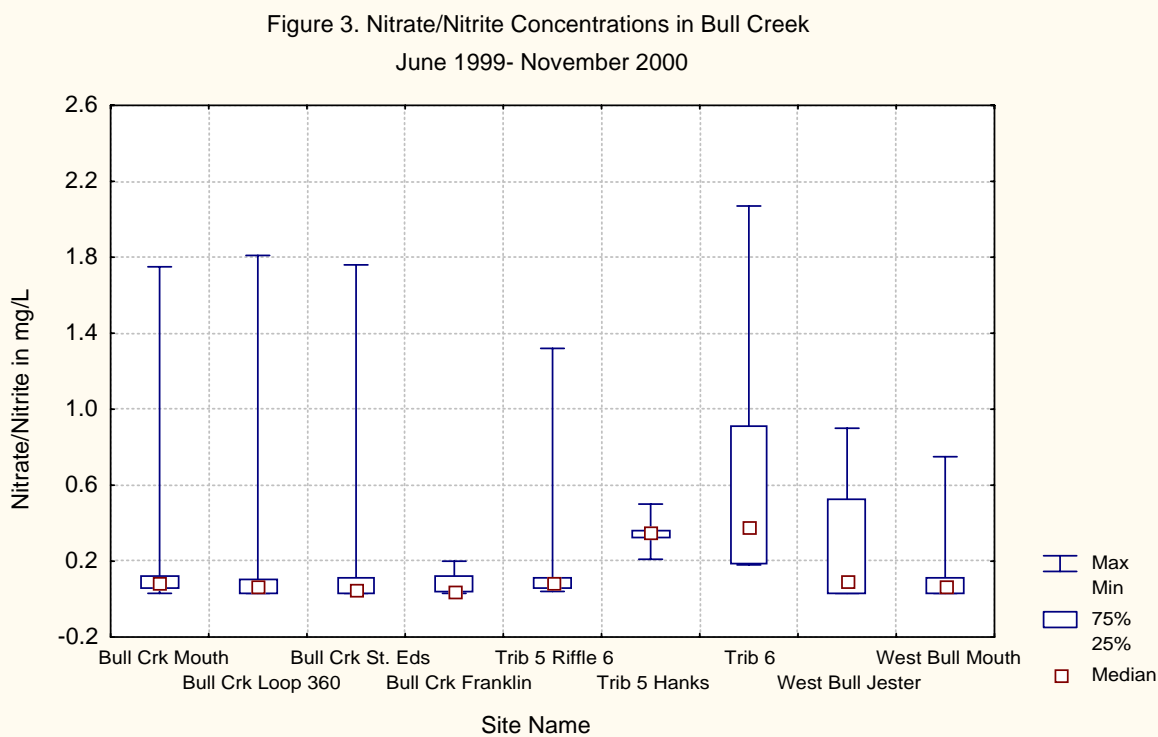
*combination of urban & rural w/ 11.4% impervious cover na - not available
 +both of these sites have < 5 percent impervious cover; however they are in proximity to both Loop 360 and RR 2222, and they receive runoff from both these roadway.

Nutrients

Nitrate and Ammonia

Median nitrate-nitrite concentrations in the mainstem of Bull Creek are generally low, below 0.2 mg/L, as shown in Figure 3. On the November 15, 2000, sampling date, nitrate concentrations were the highest recorded during the sampling period, as indicated in Figure 3 by the maximum, although still below the TNRCC screening criteria for freshwater streams of 3.5 mg/L (TNRCC, 2001). The spike in concentrations could have resulted from rainfall in the watershed after a long period of extreme drought conditions in the year 2000, with a corresponding buildup of nutrients on the surrounding watershed. Nutrient spikes such as these could contribute to algae (oscillatoria, a blue green algae) blooms reported in the Bull Creek watershed in the winter months of 2000-01. The Franklin Tract site (site #349), which is the spring-influenced canyon site located on the mainstem, along with Tributary 5 (Hanks Tract) are both classified as rural or undeveloped and did not show spikes in nitrates during the November 2000 sampling. Also, no algae blooms were reported near these sites.

The spring-influenced canyon sites show higher median nitrate-nitrite concentrations. Tributary 5 (rural) and Tributary 6 (urban) show median nitrate concentrations markedly higher than those in the mainstem and West Bull. However, far more variations in nitrate values are present in the data from the more urban Tributary 6. The site on Tributary 5 at Riffle 6 is downstream of a large pond and the confluence of Tributary 6; these nitrate concentrations are similar to concentrations in the mainstem. Aquatic vegetation in large ponds can consume large amounts of nutrients during the growing season; however, when plants die off, they can release large amounts of nitrates back to the system. The larger the variation in seasonal nutrient enrichment and biomass die off, the larger the stress incurred by the aquatic ecosystem. Median concentrations in West Bull Creek are similar to Bull Creek mainstem concentrations. The site at Jester Blvd. shows a higher level of variation in nitrate concentrations than do other sites and is similar in variation to the results seen in Tributary 6.



Ammonia concentrations measured were all less than 0.065 mg/L, with the majority being below detection limits of 0.02 mg/L. Ammonia in natural water bodies is converted to nitrite by naturally occurring bacteria and oxidizes to nitrate rapidly under aerobic conditions. Any increase in the natural

systems could be indicative of septic or sewage leaks, lawn over-fertilization, or similar watershed problems. NH_4^+ is the principal form of toxic ammonia ions. The TNRCC screening criterion (TNRCC, 2001) for freshwater streams is 0.16 mg/L and was not approached or exceeded during this period. Concentrations of ammonia should not exceed 0.05 mg/L in order to protect aquatic organisms, according to studies conducted by the Kentucky Water Quality Department (KWQD, 2001); however, ammonia toxicity is also a factor of stream pH. Two sites reported ammonia concentrations above this level at 0.065 mg/L at Bull mouth in May 2000 and Tributary 5 at Hanks Tract in November 2000.

Total Kjeldhal Nitrogen

TKN is a combination of ammonia nitrogen and organic nitrogen. Since ammonia is observed to be at or below detection limits much of the time in Bull Creek, the TKN value is primarily representative of organic nitrogen. No measured concentrations of TKN above 0.4 mg/L were found throughout the entire watershed during this sampling period, with no noticeable trends between sites or site types.

Phosphorous

Two forms of phosphorus are measured, ortho and total. Total phosphorus is a measure of all the forms of phosphorus, dissolved or particulate. Ortho (also known as soluble reactive) phosphorus is usually a measure of the soluble, inorganic fraction most directly taken up by plant cells. Phosphorus is often found to be the growth-limiting nutrient in freshwater streams, because it occurs in the least amount relative to the needs of plants; therefore, available concentrations are generally absorbed rapidly by algae and macrophytes (KY, 2001). However, in Austin area streams, the relatively high pH and calcium in area soils often limit phosphorus solubility.

Ortho-phosphorus concentrations were generally low in Bull Creek and its tributaries during this sampling period, at or below detection limits of 0.02 mg/L at the majority of sites for all sampling dates. The TNRCC screening criterion (TNRCC, 2001) for orthophosphate is 0.9 mg/L. Concentrations of OP did not exceed this level during this period. Although total phosphate concentrations are more variable, the TNRCC screening criterion for total phosphorus is 1.10 mg/L, and at no time did concentrations approach or exceed this level (TNRCC, 2001).

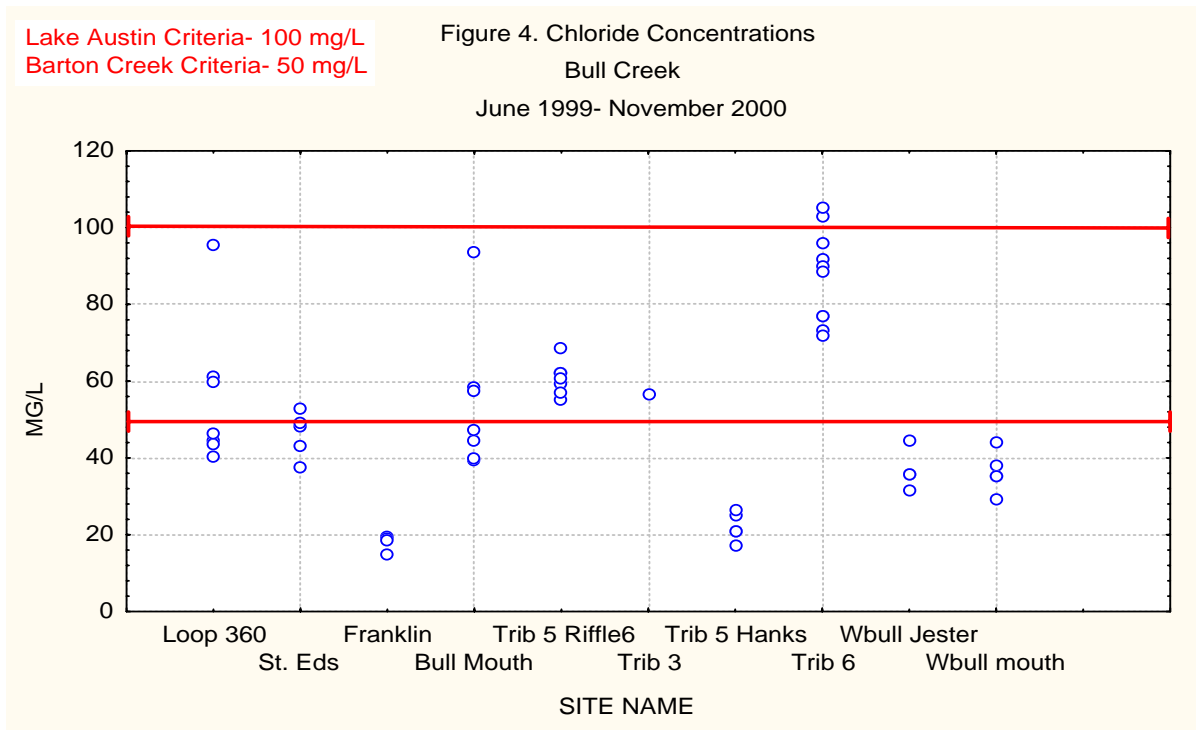
Dissolved Ions

Four sites, in Jollyville Plateau salamander habitat, were regularly sampled for dissolved ions. Of the four, the two classified as rural, Franklin Tract and Tributary 5 on Hanks Tract, have shown consistently lower concentrations of the four metals sampled than concentrations at the two urban sites, Tributary 5 Riffle 6 and Tributary 6. Tributary 5 Riffle 6 has been classified as urban because of the large influences of the Tributary 6 watershed and impervious cover. Sodium levels range from 7,478–11,654 ug/L in sites classified as rural and 31,860–55,563 ug/L in the urban sites. Levels of sodium at the rural sites were approximately one-third the levels at the urban sites. Potassium levels were approximately half the concentration, with rural sites ranging from 531 to 1,062 ug/L and concentrations of 979–3,558 ug/L for urban sites. Magnesium and calcium concentrations do not show as large a difference, but levels are noticeably less in rural sites. Magnesium at the rural sites ranged from 14,854 to 18,968 ug/L and range from 17,350 to 28,667 ug/L at the urban sites. Calcium levels ranged from 78,450 to 113,300 ug/L at rural sites and from 93,675 to 135,250 ug/L at urban sites.

According to a Kruskal Wallis ANOVA non-parametric test on the median values (selected due to non-normality of data set), all four metal concentrations are significantly lower in the two rural tributaries, with p-values lower than 0.005, both when analyzed separately and when grouped. These results might be attributable to irrigation in urban watersheds with undersaturated city tap water, which has the ability to dissolve these constituents from the limestone and native soils, thereby increasing concentrations in the spring-fed urban sites. Many sources also exist for sodium in wastewater, including water softeners, bleach, and detergents. Wastewater could influence these results through leaking lines or golf course

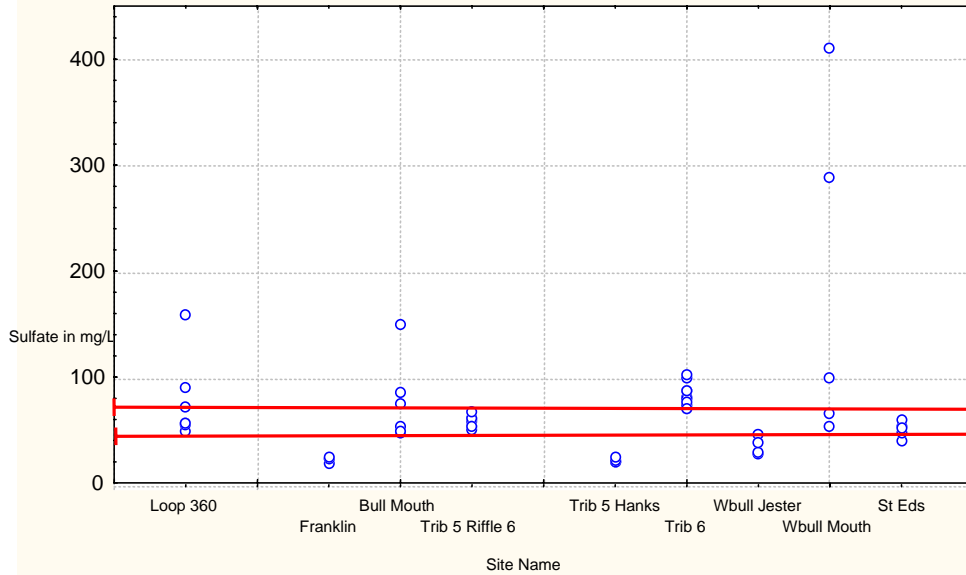
irrigation. The increase of contact between runoff and soils in disturbed landscapes common in developing areas can also cause higher amounts of in-stream dissolved solids.

All sites were analyzed for chloride and sulfate concentrations. The segment specific criteria set by TNRCC for Lake Austin is 100 mg/L chloride and 75 mg/L for sulfate, which is applied to Texas Surface Water Quality Standards TAC Title 30 Chapter 307. Directly contributing unclassified creeks such as Bull Creek and its tributaries have no specific criteria set, but historical levels in similar creeks (Barton Creek) are 50 mg/L chloride and 50 mg/L sulfate (TNRCC TAC title 30, Part 1, chapter 307). Only the urban Tributary 6 exceeded the Lake Austin criteria for both chloride and sulfate concentrations (see Figures 4 and 5). Only the rural tributaries, Hanks and Franklin, did not exceed criteria set for Barton Creek at any time (see Figures 4 and 5). Kruskal Wallis analyses of the medians show a significant difference between these two tributaries and all other sites ($p = 0.00001$). The sites on West Bull are also shown to be significantly different from the Bull Creek mainstem sites ($p=0.0011$).



Lake Austin Criteria- 75 mg/L
 Barton Creek Criteria- 50 mg/L

Figure 5. Sulfate Concentrations in Bull Creek
 June 1999- November 2000

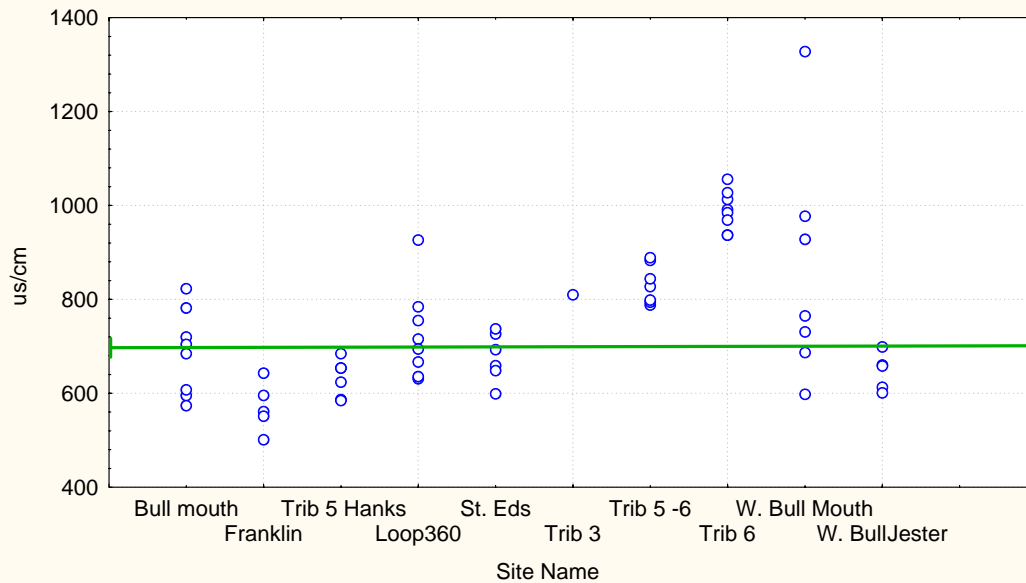


Conductivity and pH

Conductivity measurements are another indicator of dissolved ions. Total dissolved solids (TDS) is determined by multiplying conductivity by 0.65. Conductivity results vary significantly between sites, dates, and between site types in this data set, as shown in Figure 6. Franklin (#349), Hanks (#1164), and West Bull @ Jester are below the mean for the entire sampling set. Tributary 5 Riffle 6 and Tributary 6 are above the mean for entire sample set. The average of 719 us/cm for Bull Creek and tributaries and all results measured for this sample set is above TNRCC's Central Texas Plateau Ecoregion conductivity average of 425 us/cm (TNRCC, 1997). The pH averages for all sites on all sampling dates vary little within a range of 7.41 and 7.91 standard units. The TNRCC (1997) water quality criterion for pH is in the range between 6.5 and 9 standard units for Lake Austin.

Conductivity Mean= 719 us/cm

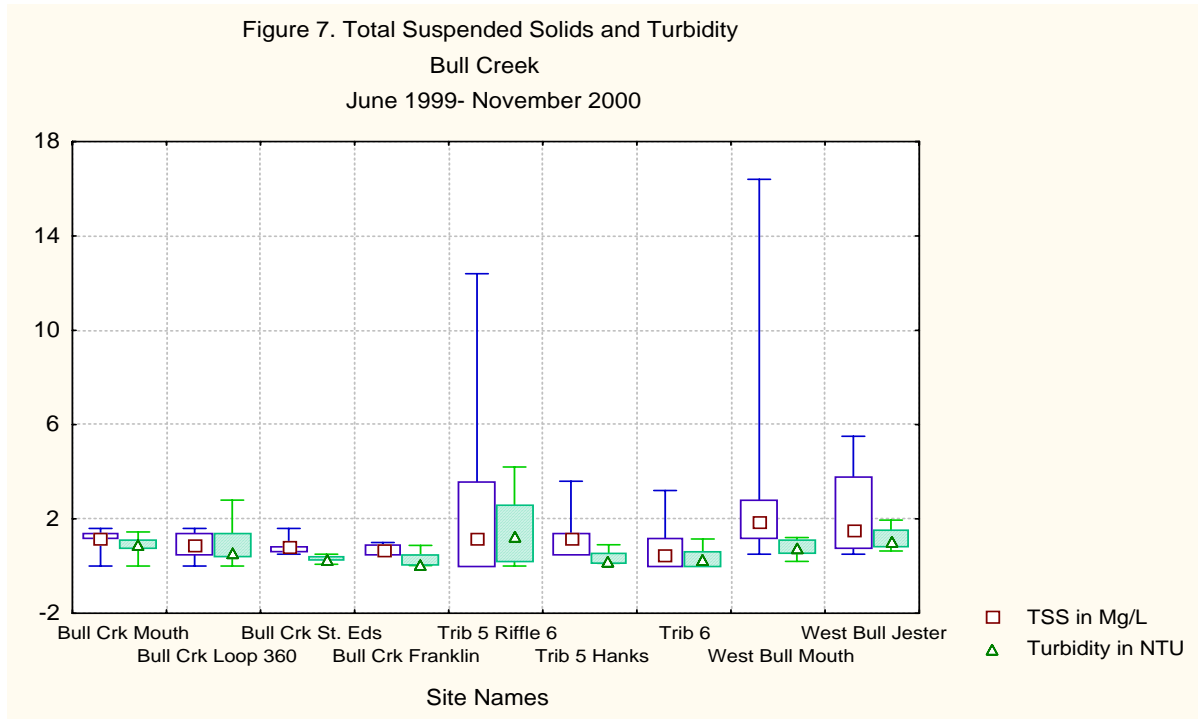
Figure 6. Conductivity
 Bull Creek
 June 1999- November 2000



Total Suspended Solids and Turbidity

Suspended solids can contribute to degradation in natural waters as they typically absorb organic and heavy metal contaminants. In addition to that released by stream channel erosion, construction runoff can release additional sediments and silts into the aquatic system. Suspended solids can also cover the gills of fish, amphibian, and macroinvertebrate species, resulting in fish kills, reduced growth rates, and in the case of many sensitive macroinvertebrates, regional extirpation. Suspended solids reduce light penetration, which reduces the ability of algae and plants to produce food and oxygen. Suspended solids settling to the bottom of a natural water body can cause physical changes in the habitat that degrade aquatic ecosystems. Sediment may smother bottom dwelling organisms, cover breeding areas, and/or smother eggs. Appendix 2 provides references on the effects of siltation on the aquatic habitat.

As is evident graphically (Figure 7), Tributary 5 Riffle 6, West Bull Mouth, and West Bull at Jester Blvd have the highest baseflow levels of TSS, with spikes in TSS occurring at West Bull Mouth and Tributary 5 Riffle 6. Corresponding higher turbidity levels occurred at the Riffle 6 site. Construction was noted in the watershed of both these sites during the sampling period.

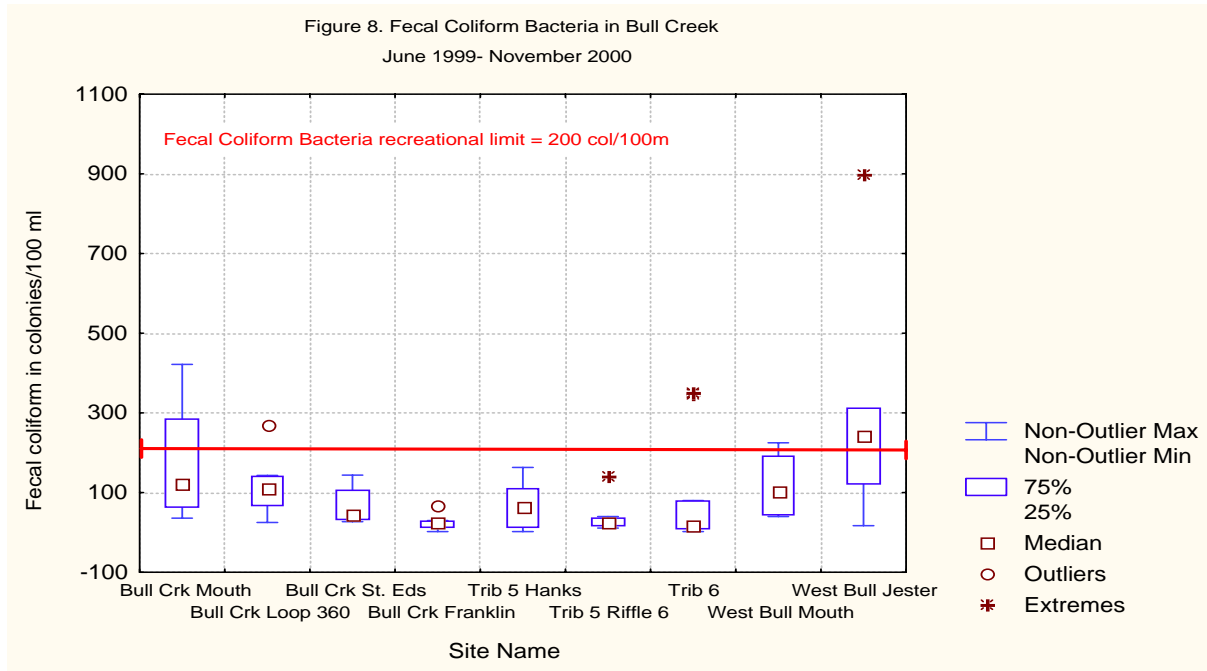


Biological Parameters

Fecal Coliform

The presence of high fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of humans or other warm-blooded animals. The criterion for swimming and recreational use is 200 colonies /100 ml on a 30-day geometric mean basis (TNRCC 30, TAC307). For fishing and boating (non-contact recreation), less than 1000 colonies/100ml is acceptable (TNRCC 30, TAC307). Bull Creek has a history of contamination by fecal bacteria; for many years

several popular local swimming holes were closed to the public due to high levels of contamination. Fecal coliform was monitored quarterly along with the water quality samples. Baseflow results are shown in Figure 8. Both mouth sites (Bull and West Bull) and West Bull at Jester have median concentrations above the limits set by TNRCC. Several sites exceed the limit on one occasion but the majority of the medians for sites during baseflow are below the recreational use limit of 200 colonies/100ml.



Habitat

The aquatic invertebrate habitat along Bull Creek's canyon tributaries is characterized by headwater springs in the upper reaches, spring runs downstream of springs and alternating riffles, glides and pools in the lower reaches. The springs provide constant baseflow in the upper reaches of the tributaries; however, the spring discharge may become intermittent during extended periods of drought, as was experienced during 2000. Substrates in the riffle areas are generally dominated by gravel and cobble that is relatively free of sand and silt. Many of these areas are underlain by solid limestone bedrock. Glides and pools provide habitat for aquatic species adapted to lentic depositional conditions. Many of the pool areas along tributaries 5, 6, and 7 are formed by artificial impoundments that have been created by the construction of low water dams or concrete low water crossings for vehicles. These structures trap silt, sediment and organic detritus that dominate the substrate and provide aquatic habitat for invertebrates, salamanders, and various species of fish (Robert Hansen, personal correspondence).

The aquatic habitats along Bull Creek's main stem have higher flows and riffles with larger surface area. Due to the width of the stream channel in the main stem, canopy cover is lower and increased exposure to sunlight occurs in both riffles monitored. Bull Creek at St. Edward's Park is characterized by a 75-foot-wide water channel with braided islands. Gravel and cobble, interspersed with seasonally large growths of aquatic vegetation dominate the streambed. Large trees on the banks provide canopy shade for parts of the channel during different times of the day. This site is buffered from roads and residences by a large park on Spicewood Springs Road. Bull Creek at Loop 360 is the most downstream site monitored for benthic macroinvertebrates. Directly downstream of the highway, the streambed is solid limestone bedrock, overlain with constantly shifting gravel and cobble substrate. Little tall vegetation is established on the

banks, as they have been cemented for construction of the roadway. Sunlight exposure at the site is unrestricted due to lack of canopy cover.

Benthic macroinvertebrates

Two sample sites are located within the Travis County BCP; Tributary 6, site #151 and Franklin Tract site #349. Previous COA monitoring has indicated that this area has a high level of biological diversity with respect to aquatic insects (COA, 1999, Robert Hansen-personal correspondence). Two sampling sites are located on the mainstem of Bull Creek, at St. Ed's. Park (site #920) and Loop 360 (site #350). During the sampling period, a new site was added, Tributary 5 Riffle 6 #1361, to try to monitor what the effects, if any, a large flood control structure will have on the habitat and aquatic populations in the channel directly upstream of this structure. Research has shown that when a dam is installed, it leads to accumulation of sediments in the area upstream of the structure (Gordon, 1992) Appendix 2 includes a discussion of the potential effects of sedimentation on macroinvertebrate and other aquatic populations. Sufficient benthic data are unavailable at this time to evaluate this site.

Benthic macroinvertebrates were collected in June and November of 1999 and May and November 2000 at three mainstem sites and one canyon site. (Sites # 349, 350, 920, and 151) Site #349 (Franklin Tract) was dry in November of 1999 and 2000. Additional macroinvertebrate samples were collected at Tributary 5 in three riffles upstream of a flood control structure before construction began in February of 2000. With completion of this structure, this site was added to the regular monitoring plan. Several other samples were collected for other COA projects in the first half of 2000 at the mainstem site at Loop 360 (#350) and are included in metric calculations and discussion. Samples were collected during baseflow conditions, both high and low flows.

Four sites during June 1999 through November 2000 resulted in 97 macroinvertebrate taxa being collected. This total taxa number is relatively high, considering the extreme environmental conditions experienced during this time period (drought 2000) and relatively small sample size (3 surfers) at each site. These macroinvertebrates were identified to genus level, with several identified to species level. The number of taxa would no doubt increase with identification of all organisms to the lower species level. Taxonomically rich groups collected during these surveys include Coleoptera (19 genera), Diptera (15 genera), and Trichoptera (15 genera). Other groups, such as Ephemeroptera (8 genera), Odonata (8 genera), and Hemiptera (6 genera) are also well represented.

A total of 12 different taxa occurred at all 4 sites, from headwaters to mouth at some time during the survey period. These groups include the 5 Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, indicating intolerance of poor water quality, *Cheumatopsyche* spp., *Fallceon quilleri* (Dodds), *Hydroptila* spp., *Perlesta decipiens* Walsh, and *Tricorythodes albilineatus* Berner. Other taxa present at all sites include *Argia immunda* (Hagen), *A. translata* Hagen in Selys, *Caloparyphus* spp., Chironomidae, *Dugesia tigrina* (Girard), Hydracarina, *Physella virgata* (Gould), and *Simulium* spp.

Total taxa numbers (between 18 and 30) are considered within the normal range for background conditions at Franklin and Loop 360. St. Edward's Park had depressed taxa values in November 1999 and November 2000, (11 and 9, respectively), which could be attributed to low flow and physiochemical conditions present at the time of the surveys. Tributary 6 had taxa values in excess of background with a total of 38 taxa in May 2000. Increasing taxa is a condition that has been associated with nutrient enrichment (Barbour, 1995). Although increased taxa numbers are normally viewed as favorable, they can represent abnormal environmental conditions such as may occur downstream from golf course fertilization or any other intensive turfgrass management. Field notes for this date indicate unusual conditions, noting a wide shallow riffle, unlike conditions noted in the past for this site. No evidence of channel alteration was found; therefore, the new streambed conditions may have been due to the system readjusting after flood events.

Several sensitive species were collected only in canyon sites (Tributary 6 site #151, Franklin site #349) on the BCP property. These include the Trichoptera taxa, *Xiphocentron messapus* Schmid, *Phylloicus ornatus* (Banks), *Nectopsyche gracilis* (Banks), and *Mayatrichia* sp. The large ephemeropteran, *Hexagenia limbata* (Serville), as well as the large megalopteran, *Corydalus cornutus* (Linnaeus), and several Hemiptera taxa were also found only at these sites.

Values for percent dominance for one taxon increased over the sampling period at all sites surveyed (Harrison, 1996). Groups for the entire survey with dominance ranging from 35 to 65 percent include *Chematopsyche* spp., *Simulium* spp., *Physella virgata*, Chironomidae, and *Fallceon quilleri*. Blackfly (*Simulium*) abundance is largely due to seasonally fluctuating populations. They are facultative ecologically and occur virtually everywhere in flowing water and sometimes exhibit great abundance even in pristine streams with excellent water quality. Increased abundance of *Simulium* are not a conclusive indicator of water quality degradation (Davis, 1986; N.A. Wiersema, personal communication).

Chematopsyche is a Trichoptera (Caddisfly) genus of the Hydropsychidae family. Among the Trichoptera, the Hydropsychidae are probably one of the most tolerant of this sensitive order. A high relative percentage of this genus in relation to other Trichoptera can possibly reflect physiochemical degradation or some kind of environmental stress (TNRCC, 1999). These caddisflies were dominant in May and June of 2000, at sites #349 and #350. *Plautidius virilis* (McDunnough) was found only at Franklin (#349) and St Edward's Park (#920). The species of the small Nearctic genus *Plautidius* are highly sensitive to nutrient enrichment (N.A. Wiersema, personal communication). *Plautidius* species have proven to be useful indicator species in the Balcones Plateau region of Texas (N.A. Wiersema, personal communication; Wiersema, 1999). *Plautidius virilis* has not been observed in the urban canyon Tributary 6.

Percent dominance for the top 3 taxa exceeded 67.8 percent at St. Ed's (#920) in November 1999 and at Franklin (#349) in June 2000. The optimal range for dominance of the top 3 taxa is below 54.6 percent according to TNRCC metric criteria (Harrison, 1999).

An index of similarity between sites was used to compare community taxonomic composition between all possible site pairs (Davis, 1999). Index values range from 0.00 when there is no commonality to 1.00 when sites are identical. Table 2 illustrates results. These sites were relatively similar during this survey period. Site # 920 – St. Edward's Park was the least similar to all other sites during this sampling period. The most upstream and least urban of the mainstem Bull Creek sites, site # 920 has a large park as buffer from roadways and development.

Table 2
Similarity Values Between Benthic Metric Scores at Bull Creek Sites

Site #	Site #	Similarity Value
151	349	0.61
151	350	0.60
151	920	0.48
349	350	0.51
349	920	0.56
920	350	0.58

As is seen in Table 3, the majority of sites score in the high and excellent range for aquatic life use when compared to other Central Texas ecosystem streams. Several scores in the intermediate range are probably due to physiochemical and environmental stressors caused by the low flow conditions of the drought.

Tributary 6 (site #151) scores in the excellent range for all survey dates, probably due to hydrological conditions. Site # 151 is the only macroinvertebrate site that never went dry during the 2000 drought.

**Table 3
TNRCC Aquatic Life Use Scoring for Bull Creek (Davis 1997)**

Sampling Date	Tributary 6- #151	Franklin -#349	Loop 360 - #350	St. Ed's.- #920
Apr-99	.	.	High	.
Jun-99	Excellent	High	High	High
Nov-99	Excellent	DRY	Intermediate	Intermediate
Feb-00	.	.	Intermediate	.
Mar-00	.	.	High	.
Apr-00	.	.	Excellent	.
May-00	Excellent	High	High	High
Jun-00	.	Intermediate	High	High
Jul-00	.	.	Excellent	.
Nov-00	Excellent	DRY	High	Intermediate

Raw metric results are available in Appendix 3.

The species of the riffle beetle family Elmidae have historically been thought of as useful indicator species. Field observations note a marked reduction in Elmidae populations at several sites during post-drought surveys.

Salamander counts were conducted from August 1999 through the present by COA personnel with assistance from the COA Parks Department and The University of Texas. Results for the three monitored sites are included in Appendix 4.

CONCLUSIONS

The undeveloped or rural sites (Franklin Tract and Hanks Tract) appear to recover quickly or are unaffected by natural environmental stressors. These two sites did not exhibit a spike in the concentration of nitrates after the drought and had no reported algae blooms during the winter following (2000-2001). They are lower in dissolved metals and conductivity. Tributary 5 and 6 are higher in nitrate concentrations during baseflow conditions. The higher nitrate concentrations are linked to naturally higher nitrates in Northern Edwards Aquifer springs feeding these tributaries.

Elevated total suspended solids concentrations and turbidity in baseflow measurements at West Bull at Jester Blvd. and the Tributary 5 site upstream of the Gardens of Bull Creek flood control structure are apparently the result of construction in the West Bull watershed and in the BCP.

Although macroinvertebrate populations appear to be similar, there are subtle differences between sites. Loss of some of the more sensitive species has occurred at sites experiencing nutrient enrichment and sediment accumulation.

RECOMMENDATIONS

Continued water quality collection and biological monitoring is recommended, especially at sites where changes in conditions are expected, such as West Bull and upstream of the Gardens of Bull Creek flood control structure in Tributary 5. The current sampling frequency of quarterly water chemistry and semiannual biological collection was found to be adequate to distinguish between sites based on watershed characteristics. Additional macroinvertebrate collections in the Hanks Tract site on Tributary 5 and on one West Bull site would be useful for comparison purposes. These changes will be evaluated in review of the monitoring plan and implemented as the budget allows.

Annual collections of deep pool and edge habitat invertebrates in the BCP sites would assist in further classification of these sites and possibly accentuate differences or similarities between site types. This method of analysis is not standardized through the Rapid Bioassessment Protocols, but may be necessary to track biological impacts on intermittent streams. It has been used under similar hydrologic conditions in Barton Creek (Davis, 1998).

In terms of addressing the degradation identified in water quality and biological parameters in the watershed, several programs are underway that will require additional time to provide tangible improvements. The City has completed a review of construction and transportation issues in the Water Supply Suburban Watersheds including Bull and West Bull Creeks. Recommendations from this analysis included several regulatory and programmatic upgrades to address this rapidly developing area. In addition, a Capital Improvement Project preliminary engineering study has been initiated to identify remaining opportunities for water quality structural retrofit projects. Monitoring of the effectiveness of these improvements should provide additional information as to the efficacy of water quality retrofits and their ability to maintain or improve sensitive aquatic habitats.

REFERENCES

Barbour, M.T., Stribling, J. B., Karr, J.R. 1995. Multimetric Approach for Establishing Biocriteria and Measuring Biological Condition, Biological Assessment and Criteria-- Tools for Water Resource Planning and Decision Making. CRC Press, Lewis Publishers, Boca Raton, Florida

City of Austin. January 1987. Austin Plan- Sector 14, Planning and Growth Management Department.

City of Austin 1999-2001. Jollyville Plateau Water Quality and Salamander Assessment, October 1999
City of Austin Water Quality Report Series COA-ERM 1999-01 Draft.

Davis, J.R. 1986, Water Quality Evaluations and use attainability analyses of six Colorado River tributaries, Hays, Travis and Bastrop counties. Texas Water Commission, Austin, Texas.

Davis, J.R. 1997. Draft. Metrics and Scoring Criteria for Surber Samples- Benthic Macroinvertebrates. Receiving Water Assessment Procedures Manual. TNRCC June 1999 Draft.

Davis, J.R. October 1999. Unpublished. Assessment of Benthic Macroinvertebrate Communities of Pool Habitats in Barton Creek, July 27-30, 1998. Surface Water Quality Monitoring Team, Texas Natural Resource Conservation Commission, Austin, Texas.

Gordon, N.D., McMahon, T.A., Finlayson, B.L. 1992. Stream Hydrology An Introduction for Ecologists. John Wiley & Sons, Inc. 605 Third Ave., N.Y., N.Y.

Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data 2002 January 2001 Draft. Texas Natural Resource Conservation Commission, Austin, Texas. Office of Compliance and Enforcement. Monitoring Operations Division Surface Water Quality Monitoring Program.

Harrison 1996. Metric and Scoring Criteria for Kick Samples, Rapid Bioassessment Protocol- Benthic Macroinvertebrates, Receiving Water Assessment Procedures Manual. Texas Natural Resource Conservation Commission, Austin, Texas. June 1999 Draft

Hax, Carolyn, 1998. American Midland Naturalist April 1998 v139 n2 p210(14)

Resh, V.M., Rosenberg, D.M. 1984. Ecology of Aquatic Insects. Praeger Publishers, 521 Fifth Ave. N.Y.N.Y.

Roell, M.J. Sand and Gravel Mining in Missouri stream systems: Aquatic Resource Effects and Management Alternatives. June 1999. Miss Dept of Conservation Columbia Ms. 65201)

Runde, J.M. April 1999. Hydrodynamic and Behavioral Responses to Sediment Transport by Hydropsyche Sparna (Trichoptera: Hydropsychidae). Dept. of Biological Science Notre Dame, Indiana Chapter 6 p.133

State of Kentucky. Natural Resources and Environmental Protection. 06/28/2001.
<http://water.nr.ky.us/ww>

Texas Natural Resource Conservation Commission 1999. Receiving Water Assessment Procedures Manual. June 1999. Draft

Texas Natural Resource Conservation Commission, Austin, Texas. (2001) TAC, Title 30, Part 1, Chapter 307.

U.S.E.P.A. July 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers. 2nd edition. #841-B-99-002. Office of Water 4305F, Washington, D.C. 20460.

Wiersema, N.A. 1999. *Plauditus texanus* (Ephemeroptera: Baetidae), a new small minnow mayfly from Texas. Entomol. News 110: 281-284.

Appendix 1 Current and Future Impervious Cover and Landuse in the Bull Creek Watershed

Table of Impervious Cover by Site

Site ID		INCREMENTAL VALUES		CUMULATIVE VALUES			
		Impervious Area (ac)	Total Area (ac)	Impervious Area (ac)	Total Area (ac)	IC	Corrected IC**
1164	Trib 5 Below Hanks Tract	34.0	834.1	34.0	834.1	4.1%	4.8%
151	Trib 6 @ Bull Creek	170.6	1,229.2	170.6	1,229.2	13.9%	16.2%
1361	Trib 5, Riffle 6	0.0	42.3	204.7	2,105.6	9.7%	11.4%
349	Bull Creek Above Trib 7	51.6	1,841.9	51.6	1,841.9	2.8%	3.3%
920	Bull Creek @ St. Eds	467.0	4,347.2	723.2	8,294.7	8.7%	10.2%
350	Bull Creek @ 360	994.2	6,183.4	994.2	6,183.4	16.1%	18.8%
347	Bull Creek Above W. Bull	66.6	417.5	1,783.9	14,895.5	12.0%	14.0%
1107	W. Bull @ Jester	150.0	3,719.8	150.0	3,719.8	4.0%	4.8%
343	W. Bull Above Bull	58.0	710.1	208.0	4,430.0	4.7%	5.5%

Land Use Key	
LLSF	Large lot single family
SF	Single family
MF	Multifamily
COMM	Commercial
OFF	Office
IND	Industrial
TRAN	Transportation
UTIL	Utility
UNDEV	Undeveloped
LU	Land use

*from cumul_ic grid created 7/01 by EW using CRWR model grid ic_current2

** corrected to include sidewalks and driveways

Table of Land Use by Site, INCREMENTAL VALUES

Site ID	LU Code: LU Name:	50	100	113	200	300	400	500	600	700	800	870	900	Total Area (ac)
		LLSF Area (ac)	SF Area (ac)	SF Area (ac)	MF Area (ac)	COMM Area (ac)	OFF Area (ac)	IND Area (ac)	CIVIC Area (ac)	PARK Area (ac)	TRAN Area (ac)	UTIL Area (ac)	UNDEV Area (ac)	
1164	Trib 5 Below Hanks Tract	0.0	42.4	0.0	0.0	0.0	6.3	16.0	0.0	214.5	31.2	0.0	523.7	834.1
151	Trib 6 @ Bull Creek	71.2	492.7	0.0	0.0	19.0	7.4	0.0	0.9	155.0	129.1	0.5	353.5	1,229.2
1361	Trib 5, Riffle 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.7	0.5	0.0	7.0	42.3
349	Bull Creek Above Trib 7	53.5	17.1	2.9	0.0	12.7	92.1	140.4	0.0	452.1	56.9	0.0	1,014.1	1,841.9
920	Bull Creek @ St. Eds	331.1	1,028.8	0.0	40.4	35.2	351.1	7.5	96.5	367.4	364.2	8.5	1,716.6	4,347.2
350	Bull Creek @ 360	4.8	1,767.9	1.9	409.7	77.6	146.0	22.7	29.7	1,556.5	650.7	2.2	1,513.9	6,183.4
347	Bull Creek Above W. Bull	0.0	131.3	0.0	1.2	0.0	3.2	0.0	0.0	80.7	64.8	0.0	136.3	417.5
1107	W. Bull @ Jester	95.4	567.9	0.0	0.0	0.0	0.0	0.0	0.0	558.6	140.3	3.6	2,353.9	3,719.8
343	W. Bull Above Bull	0.0	41.0	0.0	29.2	3.2	6.7	0.0	0.0	130.4	102.7	0.0	396.9	710.1

Table of Land Use by Site, CUMULATIVE VALUES

Site ID	LU Code: LU Name:	50	100	113	200	300	400	500	600	700	800	870	900	Total Area (ac)
		LLSF Area (ac)	SF Area (ac)	SF Area (ac)	MF Area (ac)	COMM Area (ac)	OFF Area (ac)	IND Area (ac)	CIVIC Area (ac)	PARK Area (ac)	TRAN Area (ac)	UTIL Area (ac)	UNDEV Area (ac)	
1164	Trib 5 Below Hanks Tract	0.0	42.4	0.0	0.0	0.0	6.3	16.0	0.0	214.5	31.2	0.0	523.7	834.1
151	Trib 6 @ Bull Creek	71.2	492.7	0.0	0.0	19.0	7.4	0.0	0.9	155.0	129.1	0.5	353.5	1,229.2
1361	Trib 5, Riffle 6	71.2	535.1	0.0	0.0	19.0	13.7	16.0	0.9	404.1	160.9	0.5	884.2	2,105.6
349	Bull Creek Above Trib 7	124.7	552.2	2.9	0.0	31.7	105.8	156.4	0.9	856.3	217.8	0.5	1,898.3	3,947.5
920	Bull Creek @ St. Eds	455.8	1,581.0	2.9	40.4	67.0	456.8	163.9	97.3	1,223.7	581.9	9.0	3,614.9	8,294.7
350	Bull Creek @ 360	460.7	3,348.9	4.8	450.1	144.5	602.8	186.6	127.0	2,780.2	1,232.6	11.2	5,128.7	14,478.0
347	Bull Creek Above W. Bull	460.7	3,480.2	4.8	451.2	144.5	606.0	186.6	127.0	2,860.8	1,297.4	11.2	5,265.0	14,895.5
1107	W. Bull @ Jester	95.4	567.9	0.0	0.0	0.0	0.0	0.0	0.0	558.6	140.3	3.6	2,353.9	3,719.8
343	W. Bull Above Bull	95.4	608.9	0.0	29.2	3.2	6.7	0.0	0.0	689.0	243.0	3.6	2,750.8	4,430.0

Appendix 2

Discussion on the Effects of Sedimentation on Aquatic Insects in a Freshwater Stream

Many aquatic organisms use the channel bed “substrate” as a foothold and species differ in their substrate preferences and requirements. The suitability of a substrate for colonization depends on its “average particle size, its mix of sizes, size of pore spaces, degree of packing and embeddedness and surface topography”(Gordon, 1992).

Freshwater crayfish and some aquatic insect species, such as dragonfly and stonefly larvae live in crevices between and beneath rocks. Others such as some caddisfly larvae require unstable fine grain sands. Chironomidae need mud for burrowing. Distribution of sediment sizes along a stream will be one of the physical habitat factors influencing the distribution of organisms. The highest diversity and productivity of aquatic invertebrates seems to occur in riffle habitats with medium cobble and gravel substrate, while areas of shifting sand commonly have reduced spp. abundance (Gordon 1992).

Gravel bed streams, which become filled with silt, may show a shift in the insect species composition from Ephemeroptera and Trichoptera to Chironomidae (diptera), which can in turn affect fish species composition (Gordon 1992)

“Particle size is important in determining the disturbance potential of bedload sediment. Drift increases in prevalence when larvae and retreats are completely buried by particles smaller than 1000 μm . Burial by sand is not a lethal disturbance when particles are larger than 1000 μm . Drift may be dependent on the ability of the larvae to obtain adequate oxygen when buried. This depends on temperature, water velocity, and the volume of interstitial space. Mixtures of large and small sand particles will have a greater detrimental impact than large sand particles alone because of the filling of interstitial space. The sediment loading rate is important in determining the biotic response because it determines the probability that the insects will be embedded. Stream bottoms covered with large gravel and cobble will be impacted to a lesser degree than those composed of smaller particles.”(Runde 1999)

Experimental studies have demonstrated that the primary effect of sediment addition to a stream is to initiate drift of animals from the affected site. “ Studies of the mayfly *Ephemerella subvaria* in artificial streams indicated that minor spates may initiate significant increases in drift when siltation is involved.(Resh 1984) Studies performed in Canada on the Harris River show drifting of macroinvertebrates increases with the addition of sediment to a stream. Plecoptera, Ephemeroptera, Chironomidae, Oligochaeta, Simuliidae and Hydracarina all show initial bursts of high drifting responses with sediment addition .(Rosenberg 1978) Light siltation (studies involving siltation of about 1mm) has shown a variable effect on insect communities.. It can increase the population of certain mayflies and stoneflies (*Caenis latipennis* and *Perlesta placida*) in coarse sediments.

Other studies have revealed a light layer of silt reducing the abundance of six taxa: *Alloperla*, *Arcynopteryx parallela*, *Chironomidae*, *Ephemerella grandis*, *Optioservus quadrimaculatus*, *Paraleptophlebia heteronea*, where added to a coarse substrate in a stream (Resh 1984).

In general, the effect of a heavy prolonged sediment load on streams is to reduce the number of species. and the density of animals, although some groups may take advantage of altered habitat conditions. Burrowing and deposit feeding groups like Oligochaeta and Chironomidae tend to be favored by such alteration of habitat (Resh 1984).In addition, macroinvertebrate communities inhabiting substrate composed of sediments and sands experience slower recovery after

disturbance. This may be due to relative instability of sand as compared to other substrates, such as woody debris. (Hax, 1998)

Fine silts and clays clog gills like particulate smog, reduce light for photosynthesis and periphyton production and interfere with foraging of sight feeders and filterers (Gordon 1992). Siltation may affect the inhabitability of a substrate by altering water movement, food quality, oxygen availability and interstitial spacing (Resh 1984). Sedimentation in a Texas stream reduced macroinvertebrate abundances 97% at the site and 50% up to 2 miles downstream, abundances returned to normal 3 miles downstream (Roell, 1999). Heavy metals and other toxic substances can also be adsorbed onto particulate surfaces (esp. correlated with fines) and deposited in the habitat with the sediments (Gordon 1992).

Appendix 3
Raw Metrics Scores for Benthic Macroinvertebrates

site #	Date	NUMBER OF DIPTERA TAXA	NUMBER OF EPHEMEROPTERA TAXA	NUMBER OF EPT TAXA	NUMBER OF INTOLERANT TAXA	NUMBER OF NON INSECT TAXA	PERCENT DOMINANCE (TOP 1 TAXA)	PERCENT DOMINANCE (TOP 3 TAXA)	PERCENT OF TOTAL AS CHIRONOMIDAE	PERCENT OF TOTAL AS COLLECTOR/GATHERER	PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	PERCENT OF TOTAL AS ELMIDAE	PERCENT OF TOTAL AS EPT	PERCENT OF TOTAL AS FILTERERS	PERCENT OF TOTAL AS GRAZERS (PI AND SC)	PERCENT OF TOTAL AS PREDATORS	PERCENT OF TOTAL AS TOLERANT ORGANISMS	PERCENT OF TOTAL AS TRICHOPTERA AS HYDROPSYCHIDAE
151	6/7/99	6	5	12	8	3	16.41	30.15	22.14	20.61	53.82	0	34.35	27.86	6.11	53.82	0	21.74
151	11/17/99	2	5	10	6	2	23.91	46.38	2.9	35.51	53.62	0	49.28	4.35	53.62	10.15	0	0
151	5/11/00	7	6	13	11	8	18.37	31.51	6.93	61.8	61.8	0.73	64.36	17.88	10.71	13.99	0	10.91
151	11/20/00	4	3	5	7	4	18.39	40.23	14.94	40.23	40.23	1.15	37.93	16.09	21.84	20.69	0	0
349	6/7/99	4	3	9	7	2	16.72	46.95	13.83	9.65	82.64	0	14.15	17.36	3.54	82.64	0	52.94
349	5/11/00	3	1	6	6	7	21.45	43.7	2.68	4.56	54.42	1.07	34.05	30.56	54.69	5.63	0	93.64
349	6/19/00	2	0	5	6	5	35.95	78.34	0.92	2.3	67.74	2.77	74.65	67.74	20.28	0.92	0	48.75
350	4/20/99	3	2	7	8	5	22.31	35.95	4.55	56.2	56.2	1.86	70.66	20.87	2.69	24.79	0	25.71
350	6/2/99	2	3	7	7	5	32.32	55.56	2.02	30.3	45.46	0.34	73.06	45.46	4.04	21.89	0	91.47
350	11/17/99	3	2	5	7	5	18.66	44.72	30.99	8.8	54.23	4.58	9.86	54.23	29.58	35.56	0	0
350	2/11/00	4	1	4	7	8	28.49	37.1	13.97	9.05	76.54	4.25	10.84	76.54	7.93	20.22	0	0
350	3/24/00	3	3	6	7	9	12.33	29.13	3.92	12.05	38.38	33.33	34.73	24.09	38.94	27.73	0.28	96.83
350	4/28/00	3	4	9	11	7	13.76	28.25	22.31	20.07	43.49	9.29	33.09	37.55	20.07	43.49	0	68.97
350	5/18/00	4	3	6	7	9	26.31	37.75	14.86	13.05	68.68	3.82	60.24	68.68	7.83	25.1	0	97.34
350	6/8/00	2	3	8	9	7	18.26	30.87	9.71	6.67	50.87	11.45	46.23	50.87	16.23	35.51	0	92.23
350	7/3/00	5	4	8	8	7	14.29	30.61	13.01	33.93	39.29	3.83	18.37	20.92	18.62	39.29	0	41.86
350	11/20/00	4	2	3	4	9	22.22	57.78	3.89	57.22	57.22	2.22	5	11.67	27.22	2.22	0.56	0
920	6/2/99	3	3	6	6	4	19.48	43.82	0.75	14.61	38.95	4.12	40.45	38.95	7.87	38.2	0	86.21
920	11/18/99	2	0	0	3	4	58.21	74.63	1.49	5.97	59.7	22.39	0	59.7	20.9	4.48	0	0
920	5/11/00	3	1	4	6	5	15.87	31.73	2.4	6.73	59.62	24.04	27.4	9.14	68.27	17.79	0	25
920	6/20/00	4	3	4	5	3	23.87	55.48	0.65	17.42	51.61	36.13	30.97	21.94	51.61	7.74	0	100
920	11/20/00	2	2	2	2	2	18.64	45.76	18.64	40.68	54.24	0	28.81	54.24	0	5.09	0	0

**Appendix 4
Raw Salamander Count Data for Bull Creek Stations (1999-2000)**

Site Name	DUDB#	Date	Water Parameters			Salamander Counts			
			Air Temperature	Water Temperature	Flow	<1 inch	>2 inch	1-2 inch	Total
Franklin	349	8/23/99	29.5	25.5	.	0	15	108	123
Franklin	349	12/13/99	10	18.5	0.09	0	2	0	2
Franklin	349	2/14/00	23.5	19	0.16	1	5	2	8
Franklin	349	3/24/00	26.5	22	0.185	16	20	5	41
Franklin	349	4/21/00	20.5	18.375	0.19	30	13	11	54
Franklin	349	5/24/00	26	20.375	0.215	35	7	14	56
Franklin	349	6/20/00	30	21	.	12	5	3	20
Franklin	349	7/10/00	32.5	21.5	.	8	2	32	42
Franklin	349	10/27/00	22	20.5	0.16	0	4	0	4
Franklin	349	1/24/01	14	13.6875	1.96	0	12	9	21
Franklin	349	4/19/01	20	18.125	1.82	42	9	4	55
Bull creek@									
Trib 7	149	5/25/99	23	21.56	0.626	93	35	81	209
Trib 5 Hanks	152	8/10/99	33	23.14	0.095	1	13	17	31
Trib 5 Hanks	152	9/17/99	26	21.75	.	0	8	7	15
Trib 5 Hanks	152	10/18/99	14	17	0.28	0	3	0	3
Trib 5 Hanks	152	11/13/99	21	18.3	0.22	1	4	3	8
Trib 5 Hanks	152	12/10/99	12	15.5	0.31	1	2	11	14
Trib 5 Hanks	152	1/21/00	10.5	15.5	0.38	7	13	17	37
Trib 5 Hanks	152	2/17/00	23.5	17.6	.	1	6	8	15
Trib 5 Hanks	152	3/22/00	27	21.167	0.71	0	22	5	27
Trib 5 Hanks	152	3/31/00	21	22	0.135	2	11	4	17
Trib 5 Hanks	152	4/19/00	24.5	18.6	0.213	3	12	5	20
Trib 5 Hanks	152	5/23/00	27.5	21.5	0.11	5	14	5	24
Trib 5 Hanks	152	6/21/00	28	23	.	0	6	2	8
Trib 5 Hanks	152	7/14/00	31	24	0.04	0	0	0	0
Trib 5 Hanks	152	10/27/00	23	21.6	.	0	7	6	13
Trib 5 Hanks	152	12/29/00	6	14.125	1.74	0	3	2	5
Trib 5 Hanks	152	1/26/01	16	15.5	0.55	0	29	15	44
Trib 5 Hanks	152	2/28/01	5.5	14	.	3	24	1	28
Trib 5 Hanks	152	3/23/01	30	18.2	.	5	14	6	25
Trib 6	151	10/18/99	12.5	17.5	0.03	0	4	0	4
Trib 6	151	11/15/99	21.5	19.25	0.03	0	2	2	4
Trib 6	151	12/12/99	13	13.8	0.19	0	4	0	4
Trib 6	151	1/21/00	11	15	0.2	0	16	2	18
Trib 6	151	2/17/00	25.5	19.33	.	1	20	3	24
Trib 6	151	3/20/00	25	20.3	0.58	2	19	10	31
Trib 6	151	4/19/00	24	19	0.36	3	48	3	54
Trib 6	151	5/23/00	29.5	21	0.27	5	30	9	44
Trib 6	151	6/21/00	30	22.67	.	0	12	2	14
Trib 6	151	7/14/00	36	22	0.05	0	7	3	10
Trib 6	151	8/11/00	35	24.5	.	0	8	5	13
Trib 6	151	9/14/00	29	24	.	1	0	2	3
Trib 6	151	11/1/00	24.5	20.83	0.86	0	10	7	17
Trib 6	151	12/29/00	7.5	12.5	1.35	0	8	1	9
Trib 6	151	1/26/01	15.5	14	0.75	0	6	2	8
Trib 6	151	2/28/01	5.5	13.167	.	0	18	4	22
Trib 6	151	3/23/01	30	16.5	.	0	26	6	32