BIOLOGICAL MONITORING OF CHAPEL HILL STREAMS, NORTH CAROLINA
July 2016

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Bolin Creek at Village Drive, July 2016

ATTENTION: PLEASE READ THIS SECTION FIRST

This is the 1st annual report by Eaton Scientific, following 5 annual reports by Lenat Consulting (2011-2015), on water quality and habitat quality of streams in Chapel Hill, North Carolina. This report includes biological monitoring data on Bolin Creek and Morgan Creek, and a tributary to Morgan Creek (Wilson Creek). A companion report also has been prepared for the Town of Carrboro with information on Bolin Creek. Reports to the Town of Carrboro can be obtained at the town's website.

This lengthy report might at first seem incomprehensible to the average citizen, but it is fairly easy to understand with minimal effort. The long lists of scientific names (in the appendices) are intended for specialists; they provide support for the scientific validity of conclusions about water quality.

This study uses information about freshwater macroinvertebrates – "bugs" to the non-biologist. Invertebrates are animals without a backbone; "macro" means they are large enough to be seen with the naked eye. They constitute a large proportion of the aquatic life in streams and can be used as an indicator of the health of the entire stream community. Furthermore, they are indicators of how well the stream supports fishing, swimming and other uses by Chapel Hill's citizens. The use of the macroinvertebrate community to assess stream water quality is supported by decades of scientific research. With increasing levels of pollution, we expect to see both fewer species and a shift in community structure to more tolerant groups.

To understand the summary tables, the reader must understand the terms "Taxa Richness" (especially "EPT Taxa Richness"), "NC Biotic Index" (See page 5-6) and "Bioclassifications". Streams are rated as Excellent, Good, Good-Fair, Fair, or Poor using information on the macroinvertebrate community. This report provides information on the present status of water quality in Chapel Hill's streams and looks for any temporal changes in water quality. Sites are described (with photos) in Appendices 4-5. A summary is given on page 16; summary tables are on pages 17-19.

Although long lists of species are primarily confined to the appendices, the reader will often find some species names used in the discussion, especially in regard to *tolerant* or *intolerant* species. Tables 2 and 3 provide the quickest summary this study. The Introduction, Methods and Review of Other Biological Data are largely repeated from earlier reports. Additional biological data from sites collected in previous years, but not 2016, are found in earlier reports. Flow information has been updated to include data into 2016. **Individuals who have read prior reports may wish to skip to the Results and Discussion sections**.

INTRODUCTION *[Note: Most of this section is taken from prior reports.]*

Water quality in Chapel Hill was evaluated in July of 2016 by sampling benthic macroinvertebrates at 5 sites: 2 Bolin Creek sites, 1 Morgan Creek site and 2 smaller tributaries of Morgan Creek. While Bolin Creek and Morgan Creek sites have been sampled for many years, 2016 was the first sampling event for the two Wilson Creek Sites. All sites were sampled in July.

There are several reasons for using biological surveys in monitoring water quality. Conventional water quality surveys do not integrate fluctuations in water quality between sampling periods. Therefore, short-term critical events may often be missed. The biota, especially benthic macroinvertebrates, reflect both long and short-term conditions. Since many species in a macroinvertebrate community have life cycles of a year or more, the effects of a short-term pollutant will generally not be overcome for many months, until the following generation appears.

Macroinvertebrates are useful biological monitors because they are found in all aquatic environments, they are less mobile than many other groups of organisms, and they are small enough to be easily collectable. Moreover, chemical and physical analysis for a complex mixture of pollutants is generally not feasible. The aquatic biota, however, show responses to a wide array of potential pollutants, including those with synergistic or antagonistic effects. Additionally, the use of benthic macroinvertebrates has been shown to be a cost-effective monitoring tool (Lenat 1988). The sedentary nature of the benthos ensures that exposure to a pollutant or stress reliably denotes local conditions, and allows for comparison of sites that are in close proximity (Engel and Voshell 2002).

Analysis of stream life is one way to detect water quality problems (Rosenberg et al 1986). Different kinds of stress will often produce different benthic macroinvertebrate communities. For example, the species associated with organic loading (and low dissolved oxygen) are well known. More recent studies have begun to identify the biological impacts of sedimentation and toxic stress. Identification at, or near, the species level is desirable for many groups of organisms (Resh and Unzicker 1975), and recent work by Lenat and Resh (2001) has shown the benefits of precise taxonomy for both pollution monitoring and conservation biology.

Organisms cannot always be identified at the species level, thus counts of the number of kinds of stream organisms often include identifications at higher levels (genus, family, etc.). Each different type of organism in these situations is called a "taxon" and the plural form of this word is "taxa". Thus "taxa richness" is a count of the number of different types of organisms. "EPT Taxa Richness" is a count of the taxa in the most intolerant groups. Higher EPT taxa richness is associated with good water quality; low EPT taxa richness is associated with poor water quality.

LITTLE CREEK CATCHMENT

The following overview of this catchment is modified from a report by the North Carolina Department of Environment and Natural Resources (2003): Assessment Report - Biological Impairment in the Little Creek Watershed Cape Fear River Basin.

Located in Orange and Durham Counties, Little Creek flows into the New Hope arm of B. Everett Jordan Lake, draining a 24.6-square mile area in subbasin 03-06-06 of the Cape Fear River basin. Two major tributaries, Booker Creek and Bolin Creek, drain the majority of the Little Creek catchment. The watershed includes extensive areas of residential and commercial development, as well as a portion of the campus of the University of North Carolina at Chapel Hill (UNC). As of 1999, impervious areas (such as roads and buildings) covered approximately 15 percent of the study area. This percentage has probably increased since that time. An upcoming analysis of impervious area in Little Creek will give more current information. The upper three quarters of this area lies in the Carolina Slate Belt, and streams here exhibit the narrow valleys and rocky substrates associated with this geologic zone. Little Creek and the downstream reaches of Booker and Bolin Creek are located in a Triassic basin and exhibit its characteristic broad floodplains and sandy substrates. Visual assessment suggests that most streams downstream of East Franklin Street were channelized (straightened and dredged) in the past. An OWASA (Orange Water and Sewer Authority) sewer easement follows Booker, Bolin and Little Creeks for much of their length.

Bolin Creek

The headwaters of Bolin Creek are located northwest of the intersection of Homestead Road (SR 1777) and Old NC 86 (SR 1109), north of Carrboro. Bolin Creek is joined by the following named tributaries, in order from upstream to downstream: Jones Creek, Jolly Branch, Tanyard Branch, and Battle Branch. Previous reports include information from some of the smaller tributaries not sampled in 2016, including an unnamed tributary at Severin Street, an unnamed Tributary of Tanyard Branch at Baldwin Park, Mill Race Branch, Cole Springs Branch, and Library Branch. Bolin Creek is dammed several times in its headwaters, most notably to form Lake Hogan, a 12-acre impoundment located just downstream of Old NC 86. Bolin Creek begins in a fairly undeveloped area and drains progressively more urban and developed areas in Carrboro and Chapel Hill as it flows towards its confluence with Booker Creek. Bolin Creek is approximately eleven miles long, mostly located within the planning jurisdiction of Carrboro. The 12-square mile watershed includes about half of Carrboro's downtown commercial district, the majority of Chapel Hill's central business district, and approximately 146 acres of the University of North Carolina at Chapel Hill (UNC) campus (primarily draining to Battle Branch). The stream also drains a variety of residential areas in Chapel Hill and Carrboro, and the dense commercial district along Estes Drive near University Mall.

Booker Creek

The headwaters of Booker Creek rise southwest of the intersection of Airport Road (NC 86) and Weaver Dairy Road in Chapel Hill. Booker Creek is joined by two named tributaries: Cedar Fork and Crow Branch. The mainstem of Booker Creek has been dammed to create Lake Ellen (surface area of seven acres, built in 1961) and, further downstream, Eastwood Lake (surface area of 47 acres, built in 1937). Unlike Bolin Creek, which drains progressively more developed areas as it flows downstream, most of the Booker Creek watershed is heavily developed.

In 2016, Bolin Creek, major a tributary of Little Creek, was sampled at two locations. Little Creek and Booker Creek were not sampled in 2016.

MORGAN CREEK CATCHMENT

Morgan Creek originates in a rural and residential area west of Chapel Hill, although much of this area is undergoing further residential development. It is the major tributary of University Lake. Downstream of University Lake, the stream flows through residential areas in the southern part of Chapel Hill. Major tributaries downstream of University Lake include Fan Branch and Wilson Creek. Most of the Morgan Creek catchment is located in the Slate Belt ecoregion, producing rocky streams. The Southern tributaries, however, have stream beds largely comprised of sand and gravel. These streams are similar to headwater tributaries of Pokeberry Creek in Chatham County (Lenat, unpublished data).

In 2016, one site was sampled in Morgan Creek. This report also includes data from two newly established sites, one on Wilson Creek, which flows north into Morgan Creek, and one on an unnamed tributary to Wilson Creek.

METHODS *[Note: this section is largely repeated from prior reports.]*

All collection methods are derived from techniques used by the NC Division of Water Quality (Lenat 1988). These methods have been in use by North Carolina since 1982, and have been thoroughly tested for accuracy and repeatability. More details can be found on the NCDWR Biological Assessment Branch website at: https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/biological-assessment-branch. Three of NCDWR's collection methods have been used for monitoring water quality in the Chapel Hill/Carrboro watersheds. These methods are: intensive "Standard Qualitative" collections, and more rapid" EPT" and "Qual-4" collections. These three methods are briefly described below.

Standard Qualitative Method – Overview [Bolin Creek sites 4-5 and Morgan Creek site 2]
The standard qualitative technique includes 10 separate samples and is designed to sample all habitats and all sizes of invertebrates. This collection technique consists of two kicknet samples (kicks), three sweep-net samples (sweeps), one leaf-pack sample, two fine-mesh rock and/or log wash samples, one sand sample, and visual collections. Invertebrates are separated from the rest of the sample in the field ("picked") using forceps and white plastic trays, and preserved in glass vials containing 70-95% ethanol.

Organisms are picked roughly in proportion to their abundance, but no attempt is made to remove all organisms. If an organism can be reliably identified as a single taxon in the field, then no more than 10 individuals need to be collected. Some organisms are not picked, even if found in the samples, because abundance is difficult to quantify or because they are most often found on the water surface or on the banks and are not truly benthic.

Organisms are classified as Abundant if 10 or more specimens are collected, Common if 3-9 specimens are collected, and Rare if 1-2 specimens are collected.

Qual-4 Method – Overview [Smaller tributary sites]
The Qual-4 method uses the same 4 samples as the EPT method, but all benthic macroinvertebrates are collected. NCDWR uses this method to evaluate small streams (drainage area < 3 square miles) and assigns ratings based solely on the biotic index values. This method is intended for use, however, only in perennial streams. For this reason, the majority of bioclassifications assigned to the Chapel Hill tributaries are tentative ratings supplemented by best professional judgment.

Assigning Bioclassifications - Overview
The ultimate result of a benthos sample is a bioclassification. Bioclassifications used by NCDWR are Excellent, Good, Good/Fair, Fair or Poor for standard qualitative samples; they are based on both EPT taxa richness and the biotic index values. A score (1-5) is assigned for both EPT taxa richness and the NC biotic index. The final site classification is based on the average of these two scores. In some situations, adjustments must be made for stream size or the season, but such adjustments were not required for this study.

EPT Criteria
The simplest method of data analysis is the tabulation of species richness (number of species), as species richness is the most direct measure of biological diversity. The term EPTS means the number of EPT taxa collected at a site. The association of good water quality with high species (or taxa) richness has been thoroughly documented. Increasing levels of pollution gradually eliminate the more sensitive species, leading to fewer EPT taxa. A score from 1 to 5 is assigned to each site, with 1 for Poor EPT taxa richness and a 5 for Excellent EPT taxa richness (see below).

The relationship of total taxa richness to water quality is nonlinear, as this metric may increase with mild enrichment of nitrogen and/or phosphorus. Taxa richness for the most intolerant groups (Ephemeroptera + Plecoptera + Trichoptera) is more reliable, but must be adjusted for ecoregion.

Biotic Index Criteria
To supplement EPT taxa richness criteria, the North Carolina Biotic Index (NCBI) was derived as another (independent) method of bioclassification to support water quality assessments (Lenat 1993). This index is similar to the Hilsenhoff Biotic Index (Hilsenhoff, 1987) with tolerance values derived from the NC database. Biotic indices are based on a 0-10 scale, where 0 represents the best water quality and 10 represents the worst. Abundance values used in the biotic index calculation are 10 for Abundant taxa, 3 for Common taxa, and 1 for Rare taxa. The highest values (>5.1) indicate the worst water quality and receive a score of 5; the lowest values indicate Excellent water quality and receive a score of 1 (see below)

NC Division of Water Resources: Scoring for Biotic Index and EPT taxa richness values for Piedmont streams

Score	BI Values	EPTValues
5	<5.14	>33
4.6	5.14-5.18	32-33
4.4	5.19-5.23	30-31
4	5.24-5.73	26-29
3.6	5.74-5.78	24-25
3.4	5.79-5.83	22-23
3	5.84-6.43	18-21
2.6	6.44-6.48	16-17
2.4	6.49-6.53	14-15
2	6.54-7.43	10-13
1.6	7.44-7.48	8-9
1.4	7.49-7.53	6-7
1	>7.53	0-5

Derivation of Final Bioclassification for Standard Qualitative Samples
For most mountain, piedmont and coastal plain (Coastal A) streams, equal weight should be given to both the NC Biotic Index value and EPT taxa richness value in assigning bioclassifications. For these metrics, bioclassifications are assigned from the following site scores:

Excellent: 5 Good: 4 Good-Fair: 3 Fair: 2 Poor: 1

"Borderline" values are assigned near half-step values (1.4. 2.6, etc.) and are defined as boundary EPT values ±1 (except coastal plain), and boundary biotic index values ±0.05. The two ratings are then averaged together, and rounded up or down to produce the final classification. When the EPT and BI score differ by exactly one unit, the EPT abundance value is used to decide on rounding up or rounding down.

Small Stream Criteria
Small streams (<4 meters wide) are expected to have lower EPT taxa richness relative to larger streams. NCDWQ (now NCDWR) has developed criteria for small piedmont stream based solely on biotic index values:

Bioclass	BI Values
Excellent	<4.3
Good	4.3-5.2
Good-Fair	5.2-5.9
Fair	6.0-6.9
Poor	>6.9

Small Stream Criteria were developed only for perennial streams – streams with water all year. *Most of the Chapel Hill small streams are intermittent and thus cannot be rated.*

Toxicity Assessment Using Chironomidae Deformities

When there are large numbers of the chironomid, *Chironomus*, the degree of in-stream toxicity can be evaluated by tabulating deformities of its mouthparts. This situation has been documented only in lower Booker Creek. The technique was developed (Lenat 1993) to help separate out the effects of low dissolved oxygen from any toxic effects when both types of stress might be occurring at the same site. *Chironomus* is associated with organic loading and low dissolved oxygen, but high numbers of mentum deformities are observed only when there is also some degree of toxicity. A "toxic score" is calculated using both the percentage and severity of the deformities. The following Toxic Score criteria are derived from Lenat (1993):

Non-Toxic: <20
Toxic fair: 20-70
Toxic Poor: >70

SAMPLING SITES (Appendix 3)

Evaluations of each sampling site are summarized on pages 14-16, and more detailed site descriptions (with photos) are presented in Appendices 4-5. See Figure 1 in Appendix 3 for a map that shows the locations of the sites sampled in 2016.

Table 1 provides data on habitat ratings and substrate composition at all sites sampled in 2016. The habitat rating is based on standard NC Division of Water Resources procedures, and produces a value between 0 and 100. A higher value indicates better habitat quality. Abundant growths of filamentous algae were observed at many sites in March 2011, but such growths were not seen in later collections. With the exception of the Triassic sites, most Chapel Hill streams had adequate habitat to support a diverse benthic macroinvertebrate community.

FLOW DATA

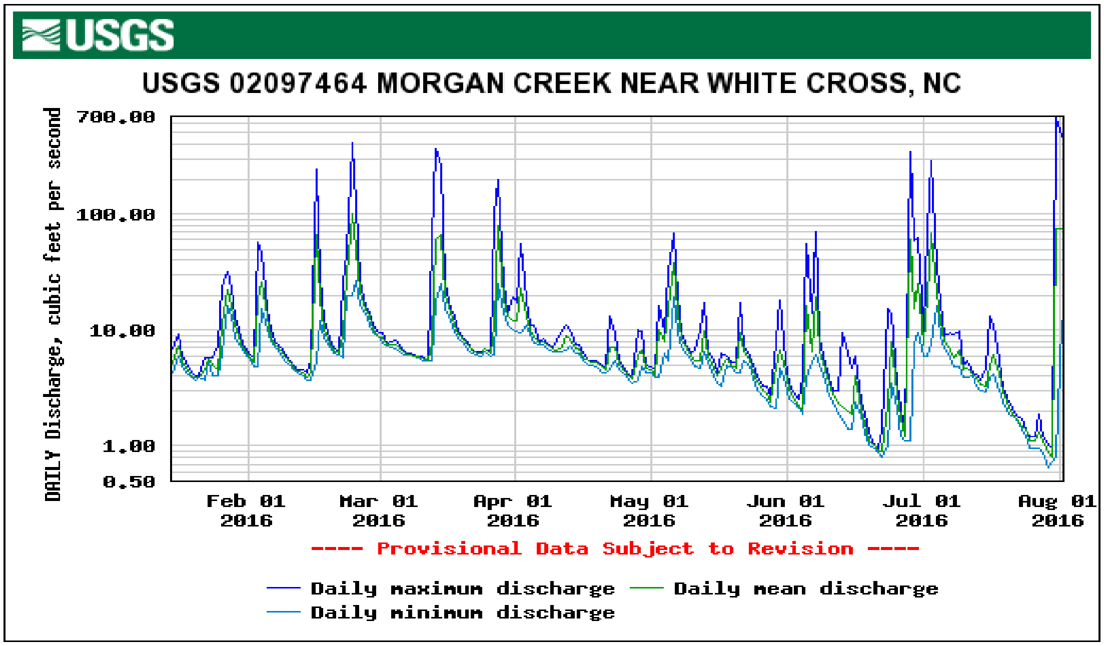
The fauna of Chapel Hill streams have been frequently affected by droughts, with some streams becoming entirely dry during severe droughts. Changes due to water quality problems cannot be discerned without taking into consideration this natural stress. The data below is taken from the USGS web site for the gage Morgan Creek at NC54 near White Cross using daily flow data from 1999 to 2015.

Low flows (less than 0.5 cfs) are highlighted in yellow; severe low flows (less than 0.1 cfs) are highlighted in red. Summer flows for 2014 were much higher than for 2004-2013; 2013-2015 fall/winter/spring flows were relatively high. Monthly mean data is not available past September 2015, but the following graph shows daily flows for 2016. This combined data suggests adequate winter and spring flows in 2015 in the Carrboro/Chapel Hill area.

Mean Monthly Flow (cfs) in Upper Morgan Creek (similar to Bolin Creek), 1999-2015.

Morgan Creek near White Cross (Drainage area 8.3 square miles)

Year	Month: 1	2	3	4	5	6	7	8	9	10	11	12
1999	13	4	5	10	0.9	0.5	0.4	0.09	40	8	7	4
2002	7	4	4	2	0.7	0.03	0.04	0.01	0.04	6	4	15
2003	6	20	32	39	11	7	6	3	2	2	2	5
2004	2	8	5	4	3	0.4	0.7	5	7	2	4	3
2005	7	7	15	6	2	0.7	0.3	0.2	0.01	0.2	0.6	7
2006	3	2	2	2	0.7	1.7	5	0.08	0.5	1.9	16	6
2007	13	7	9	12	1.8	0.6	0.2	0.002	0.000	0.008	0.003	0.2
2008	0.4	1.3	9	6	2	0.4	1.6	4	15	0.3	1.4	9
2009	5	3	19	6	3	4	0.4	0.2	0.05	0.05	7.7	18.7
2010	13	21	7	3	4	0.6	0.1	0.02	0.6	0.3	0.6	0.8
2011	0.7	1.4	3	4	1.1	0.1	0.6	0.004	0.01	0.03	1.5	3
2012	2	3	7	3	2	0.5	0.2	0.3	8	0.8	0.5	0.8
2013	7	9	4	6	9	8	13	4	0.7	2*	1*	8*
2014	15	13	21	15	12	0.8	0.3	1.1	0.3	0.6	1.6	4.8
2015	6.7	7.1	14.5	13.5	2.7	1.2	1.0	0.09	1.2			



Flow data from further downstream on Morgan Creek at Chapel Hill (41 square miles) did not indicate any months with average flows less than 7 cfs (1999-2015).

Table 1. Site characteristics, Chapel Hill Streams, July 2016, Orange County.

	Habitat Scoring (0-100)										Substrate (%)					
Stream	CM	IH	BS	PV	RH	BSV	LP	RVZW	Total	Width (m)	B	R	Gr	Sa	Si	Comments
Slate Belt (Rocky)																
Bolin Cr #4	4	15	15	6	16	3/7	9	5/2	82	8	30	20	20	20	10	Rocky. Downstream of Carrboro.
Bolin Cr #5	3	11	11	10	3	6/5	10	1/4	65	10	20	10	10	60	Tr	Rocky, near Franklin St, but sandy upstream.
Morgan Cr #2	5	15	12	10	16	7/7	10	5/4	91	7	30	40	20	10	Tr	Flow only in riffles.
Sandy Transition Streams																
Wilson Cr 1A	5	14	14	8	14	3/5	7	5/5	80	2	-	-	10	90	Tr	Behind Strata Solar. Below Obey Cr development outfalls.
UT Wilson Cr	5	11	14	6	12	6/7	10	5/5	81	0.8	Tr	10	60	30	Tr	Undeveloped tributary to be preserved.

Habitat Components: CM = Channel Modification (0-5), IH = Instream Habitat (0-20), BS = Bottom Substrate (1-15), PV = Pool Variety (0-10), RH = Riffle Habitats (0-16), BSV = Bank Stability and Vegetation (0-7 for both left and right banks), LP = Light Penetration (0-10), RVZM = Riparian Vegetative Zone Width (0-5 for both left and right banks).
Substrate: Boulder (B), Rubble (R), Gravel (Gr), Sand (Sa), Silt (Si), Tr = Trace (<10%). Stream width is in meters.

Table 2. Water chemistry data, July 2016. Dissolved Oxygen (DO, mg/l), Conductivity (umhos/cm), and Temperature (^{o}C).

Site	DO	Conductivity	pH	Temperature
Bolin Cr				
Site 4, Village	8.1	139	7.2	24.2
Site 5, Franklin St	7.6	197	6.8	24.4
Morgan Cr				
Site 2, Ashe Pl	7.0	134	6.7	26.6
Wilson Cr				
1A, Obey Cr development	7.9	126	6.6	26.7
UT, upstream 1A	7.9	122	6.9	24

High conductivity values were often associated with urban runoff and impervious surfaces: lower Bolin Creek.

PRIOR BIOLOGICAL DATA (Largely unchanged from 2015 report)
Benthic macroinvertebrates have been collected in Orange County for over 30 years. One of the first publications was a list of species found in Cane Creek, prior to the existence of the Cane Creek Reservoir (Lenat 1983). The NC Division of Water Quality has multiple collections from Morgan Creek and Bolin Creek, including both standard qualitative and EPT samples. EPT samples use a shorter 4-sample method (vs. 10 samples for the standard qualitative), and are limited to the Ephemeroptera, Plecoptera, and Trichoptera (see Methods).

The following data are taken from the Cape Fear River basin report (NCDWQ 2003) with more recent NCDWR data from Morgan Creek at NC 54 included as well:

NCDWR data, 1985-2013. Standard Qualitative and EPT samples.

	Date	Total S	EPTS	BI	Bioclass*
Bolin Cr at SR 1777	7/01	87	24	5.96	Good-Fair
	2/01	82	17	6.40	Not Rated
	4/00	-	26	-	Good
	3/98	-	23	-	Good
	4/93	-	24	-	Good
Bolin Cr at Village Rd	3/02	40	7	7.00	Fair (follows Drought)
	7/01	52	9	6.6	Fair
	2/01	54	6	7.00	Poor
	2/98	59	26	5.1	Good
	4/93	-	24	-	Good-Fair
Bolin Cr, E Franklin St	7/01	41	4	6.9	Poor
	3/01	53	4	7.1	Poor
	3/98	37	13	6.3	Fair
	2/98	-	4	-	Poor
	2/93	32	8	6.5	Fair
	4/86	89	28	6.1	Good-Fair
Booker Cr, Piney Mtn Rd	7/01	35	4	6.1	Not Rated
	2/01	39	8	6.3	Not Rated
	3/98	-	10	-	Fair
Booker Cr, Barbara Ct	7/01	45	3	6.6	Not Rated
	2/01	31	4	7.3	Not Rated
Booker Ct, Walnut St	7/01	31	4	7.3	Not Rated
	2/01	51	7	6.9	Not Rated
Morgan Cr, NC 54	06/13	-	19	-	Good-Fair
	03/09	-	26	-	Good
	03/08	-	12	-	Not Rated (Drought)
	06/04	-	18	-	Good-Fair
	10/03	-	22	-	Good
	7/03	-	20	-	Good-Fair
	5/03	-	16	-	Good-Fair
	3/03	-	12	-	Not Rated (Drought)
	1/03	-	8	-	Not Rated (Drought)
	9/02	-	2	-	Not Rated (Drought)
	4/00	-	36	-	Excellent
	2/98	80	33	4.4	Excellent
	10/96	64	22	5.0	Good
	7/93	61	22	4.9	Good
	2/93	90	36	4.5	Excellent
	4/85	109	32	5.7	Good

	Date	Total S	EPT S	BI	Bioclass*
Morgan Creek near the Botanical gardens	3/98	46	20	6.1	Good-Fair
	4/93	-	16	-	Fair
	2/93	71	26	6.0	Good-Fair
Little Cr at Pinehurst Dr	7/01	27	5	6.8	Not Rated
	3/01	45	3	7.3	Poor
	2/93	37	7	7.1	Fair

*DWQ did not assign ratings to streams in the Triassic basin, pending development of criteria for this ecoregion.

NC Department of Environment and Natural Resources (2003) provided the following summary of the Bolin Creek data:

> "When Bolin Creek was first sampled at East Franklin Street in 1986, the benthic community was reasonably diverse, and the stream, though showing indications of impact, was not considered impaired. Impairment was evident when the stream was next sampled in 1993 and has persisted at this downstream site. Upstream sites supported a reasonably intact benthic fauna until 2000, when impairment became evident as far upstream as Waterside Drive in Carrboro, located between Homestead Road and Estes Drive Extension. It is probably too soon to evaluate whether this decline in the benthic community is persistent, or was due to a specific perturbation from which this portion of the stream will yet recover. Currently, only the upper portion of Bolin Creek (Homestead Road) appears to support an adequate benthic fauna.
>
> The causes of impairment in the portion of Bolin Creek between Airport Road and Waterside Drive are less clear than in the downstream section of Bolin Creek. In-stream habitat is adequate. Some effects of toxicity and scour are likely, although these impacts appear less pronounced than in lower Bolin Creek, and likely decline significantly at the upstream end of this section."

NCDWQ collections from Morgan Creek at NC54 in 2002 and 2003 were intended to show recovery from the 4-month drought. These data indicate that the stream took about one year to recover from extreme low flow. It had shown a decline over time, never attaining the very high EPT taxa richness values seen in 1985, 1993, 1998, and 2000.

RESULTS AND DISCUSSION (Tables 3-4, Appendices 1-2)

<u>Long-term trends in Bolin Creek</u>. Early samples from Bolin Creek (prior to 2000) indicated Good water quality in the upper section, declining slightly to Good-Fair further downstream. Surveys in 2000, however, produced a Fair rating for sites at Waterside Drive (#3) in Carrboro, and at Estes Drive (#4) in Chapel Hill. It appears that nonpoint source runoff had a significant negative effect on water quality in Bolin Creek between 1998 and 2000. Note that changes in habitat were not responsible for any these water quality changes.

After August 2001, Bolin Creek was potentially affected by a series of severe droughts, with very low flows (see USGS flow data for Morgan Creek) in:

-Sept-Dec 2001 (4 months, with lowest flow in Oct-Nov)
-June-Sept 2002 (4 months with streams drying up much of this time)
-June 2004
Note that 2003-2004 would be expected to be a period of recovery.
-July-Oct 2005 (4 months with streams going dry in September)
-Aug 2006
-July-Dec 2007 (6 months, with streams going dry for 4-6 months)
-June and September 2008 – no streams went completely dry. Another period of possible recovery.

-July-Oct 2009 (4 months with severe drought for 2-3 months)
-June-August 2010 (severe drought in August)
-August-November 2011
-August 2015

These repeated shocks to the stream biota would be expected to severely affect the diversity of the stream fauna, and bioclassifications based on taxa richness counts might underestimate water quality conditions. The repeated Fair and Poor rating assigned to much of Bolin Creek in Carrboro and Chapel Hill during this period have been used to show that Bolin Creek does not support designated uses, but note that some intolerant species were still abundant at most Bolin sites through 2016.

Routine sampling in Carrboro and Chapel Hill had been switched from summer months to winter/spring months to avoid these periods of extreme low flow. In 2012-2015, tributaries were sampled in April and the larger streams were sampled in June. Note that June collections may miss some of the spring species, which may have emerged in April and May. "Emergence" is the natural process of going from the aquatic nymph to the aerial adult. In comparing data from March 2011 with June samples, some species may disappear due to emergence, rather than being lost due to a change in water quality.

Table 2 presents a summary of the biological monitoring for Chapel Hill streams for 2016. A list of selected intolerant species is presented in Tables 4A and 4B, producing a score (the "Sum" line) that is useful in comparing sites. Species are only included in Tables 4A and 4B that were Common or Abundant at one or more sites. Although scientific names are used in the latter tables, you can simply consider these as "intolerant species #1" through "intolerant species #16".

Site Evaluations

It is important to realize that drought conditions during some years make it difficult to accurately rate water quality in Chapel Hill streams. *Repeated drought conditions have resulted in very low flow rates, with some streams going completely dry. This would be expected to reduce the diversity of the fauna, but would have less effect on the tolerance of the aquatic fauna. For this reason, more emphasis is placed on biotic index ratings than taxa richness ratings. Flow conditions have improved in the last 4 years (2013-2016).*

The NCDWR system for rating small piedmont and mountain streams relies entirely on biotic index values, but note that it is not intended to apply to intermittent streams.

Large Streams

(Note: Bolin Creek sites 1-3 and Morgan Creek site 1 are in Carrboro; they are discussed in a separate report.)

Bolin Creek Site 4 (Village Drive). This site is intended to be equivalent to the Estes Drive site that has been monitored by the Town of Carrboro since 2000 and was also sampled by the NC Division of Water Quality from 1993-2002. When all sources of data are combined, the pattern clearly shows a large decline in water quality for the period between 1998 and 2001.

The Estes Drive/Village Drive site had usually received a Fair rating during drought years, but recovered to Good-Fair in July of 2009. The return of severe summer-drought conditions in 2010 and 2011, however, brought the bioclassification for this segment of Bolin Creek back down to Fair for all collections through 2014. The biotic index for this segment of Bolin Creek was significantly higher (6.7-6.8) in 2011 and 2012 relative to prior collections (5.8-6.4), but the 2013-2015 collections again produced a lower biotic index (5.8-6.3). This suggests some recovery, largely due to the appearance of the intolerant caddisfly, *Chimarra*. Recovery was also evident by the increased abundance of the intolerant snail, *Elimia*, in 2015. The 2014 collection produced a rating right on the borderline between a Fair and a Good-Fair rating, but the Good-Fair rating was not achieved until 2015. 2016 showed a return to 2014 borderline conditions – if one more EPT had been collected the site would have rated Good-Fair.

The abundance of the snail *Physa* in both 2011 and 2012 indicated that this segment of Bolin Creek had experienced low dissolved oxygen concentrations, but this problem was not evident in 2013-2016.

An additional, more subtle, metric is EPTN – the number of individual EPT (intolerant taxa) collected at a site. This metric can give more information than just the EPTS – the number of EPT taxa. For example, if one site had 5 EPT taxa that were all Rare, the EPTN would be 5. If another site had an EPTS of 5, but they were all Abundant, that would give an EPTN of 50. This could be interpreted that the site with EPTN=50 had slightly better water quality than the site with EPTN=5 since more intolerant animals are able to live there.

Date	Total S	EPT S	BI	EPTN	Bioclass
7/16	63	11	6.1	71	Fair
6/15	53	12	5.8	69	Good-Fair
6/14	57	10	6.3	64	Fair
6/13	33	6	5.9	53	Fair
6/12	52	8	6.8	48	Fair
3/11	58	8	6.7	21	Fair
3/10	42	9	5.8	35	Fair
7/09	58	10	6.2	73	Good-Fair
12/08	44	12	5.9	63	Fair
8/06**	21	6	-	19	Poor?
9/04**	25	8	-	46	Fair
9/03**	25	8	-	48	Fair
3/02*	40	7	7.0	-	Fair (follows Drought)

7/01*	52	9	6.6	-	Fair
2/01*	54	6	7.0	-	Poor?
9/00**	45	4	-	26	Poor
2/98*	59	26	5.1	-	Good
4/93*	-	24	-	-	Good-Fair

*DWQ data, 1993 collections were limited to EPT taxa
**Early Carrboro data, Ecological Consultants/Pennington. Bioclass based only on EPT Taxa richness

Bolin Creek Site 5 (Franklin Street). This site received a Poor bioclassification in 2011, similar to DWQ collections in 1998 and 2008. In 2012-2015, however, the Franklin Street site was assigned a Fair bioclassification, indicating a modest improvement in water quality. The abundance of one intolerant caddisfly (Chimarra), from 2012-2016, supported the higher rating. This site is quite sandy upstream of the bridge area, but DWQ collections in 1986 demonstrated that habitat for this site is capable of supporting a Good or Good-Fair aquatic fauna. Urban runoff (toxics) is the most likely cause of problems in lower Bolin Creek. This is a common pattern for streams draining major cities throughout North Carolina. EPT taxa richness in 2014-2015 was the highest since 1998, however in 2016, EPTS declined slightly.

Date	TotalS	EPTS	BI	Bioclass*
7/16	62	7	6.4	Fair
6/15	46	9	5.9	Fair
6/14	48	8	6.8	Fair
6/13	34	4	6.2	Fair
6/12	30	5	6.5	Fair
3/11	50	4	7.2	Poor
7/01*	41	4	6.9	Poor
3/01*	53	4	7.1	Poor
3/98*	37	13	6.3	Fair
2/98*	-	4	-	Poor
2/93*	32	8	6.5	Fair
4/86*	89	28	6.1	Good-Fair

*DWQ data

Morgan Creek Site 2 at Ashe Place (near the NC Botanical Garden). Prior DWQ sampling (1993, 1998) produced a Good-Fair rating for this site. Collections from March 2011 produced only a Fair bioclass, but the fauna had some common or abundant intolerant species, including *Isonychia*, *Chimarra*, and *Psephenus herricki*. The June 2012-2013 collections also resulted in a Fair bioclassification, but the only abundant intolerant species was *Chimarra*. This site improved to Good-Fair in 2014 - 2016, although some taxa (esp. *Isonychia*) have not returned. Much of the increased EPT taxa richness was due to the appearance of a more diverse array of baetid mayfly species (6), including *Baetis pluto* and *Acentrella nadineae.*

Morgan Creek had a bloom of bright green filamentous algae during the March 2011 collections, but this problem was not observed in later collections.

Date	Total S	EPT S	BI	Bioclass*
7/16	75	17	6.3	Good-Fair
6/15	-	15 (17*)	-	Good-Fair
6/14	58	17	6.1	Good-Fair
6/13	50	9	6.6	Fair
6/12	39	9	6.3	Fair
3/11	63	12	6.7	Fair
3/98**	46	20	6.1	Good-Fair
4/93**	-	16 (18*)	-	Good-Fair
2/93**	71	26	6.0	Good-Fair

*Converted to equivalent full-scale sample
**DWQ data

Small Streams

Many small stream sites have been regularly sampled from 2011 - 2015, however sampling in Chapel Hill in 2016 was later than usual (July) and very limited. Hopefully regular spring monitoring of small streams will resume in 2017 allowing a better long-term assessment of water quality. Some differences between years, however, can result from small changes in stream temperature, causing a change in either the time of emergence or the hatching of eggs.

Wilson Creek. Over the past five years, Wilson Creek has been monitored at two locations, above Wave Rd, near the Chatham County line, and above Arlen Park Drive. Wilson Creek appeared to be affected by sedimentation, but the sand/gravel substrate may actually reflect local geology. Similar streams have been observed a little further south in the headwaters of Pokeberry Creek in Chatham County (Lenat, unpublished). The lower end of Wilson Creek is located in a high-density residential area, but most of the catchment is comprised of heavily-forested older residential areas with large lot sizes.

	Wilson 1			Wilson 2				
	2012	2013	2015	2011	2012	2013	2014	2015
Total Taxa Richness	45	50	43	45	47	38	41	47
EPT Taxa Richness	23	20	17	17	19	11	16	22
EPT Abundance	103	104	68	54	54	17	54	122
NC Biotic Index	4.0	4.1	3.8	6.0	5.3	6.0	5.0	4.3
Rating	Ex	Ex	Good	G-F	Good	G-F	Good	Ex

Sampling in Wilson Creek in 2016 was more closely related to the Obey Creek Development, and two new sites (Wilson 1A and UT Wilson) were established. Wilson 1A is located almost midway between sites Wilson 1 and 2 and near the downstream end of the proposed development. The catchment here is approximately 1.7 mi^2 with a watershed that was 74% forested and 10% developed, based on 2011 land use data. UT Wilson Creek was a sample on the largest tributary in this segment of stream and has a watershed of 0.2 mi^2 (130 acres). UT Wilson Creek is perennial, which is uncommon for streams this small in either the Slate Belt or the Triassic Basin. Since the stream temperature was nearly 3^oC cooler than nearby Wilson Creek, it is possible that the stream is spring fed. The plan for the Obey Creek development is to preserve this stream and its watershed. Land use data from 2011 showed the watershed was 95% forested and <3% developed.

	Wil 1A	UT Wil
Ephemeroptera	3	2
Plecoptera	2	1
Trichoptera	7	7
Coleoptera	7	8
Odonata	3	4
Diptera; Misc.	4	5
Diptera: Chironomidae	5	3
Oligochaeta	2	2
Crustacea	0	0
Mollusca	2	1
Other	2	2
Total Taxa Richness	38	35
EPT Taxa Richness	12	10
EPT Abundance	47	79
Biotic Index	5.5	4.2
BI Score	3	1
Rating (tentative)*	G-F	Ex

*Small Stream ratings are for collections made in the spring. These samples were collected in the summer, under more stressful conditions. Spring sampling could yield improved ratings.

Summary and Conclusions

Larger Streams

Current Status and Short-term Changes. Bolin Creek always shows a decline in water quality between Village Drive and Franklin Street, going from Good-Fair to Fair or from Fair to Poor. In other words, there is usually a decline of one bioclassification between the upstream and downstream sites on Bolin Creek. In 2016, the upper site, while rated Fair, was one individual EPT short of a Good-Fair rating, while the lower site was solidly rated as Fair.

Long-term Changes. Some of the larger sites (Bolin Creek and Morgan Creek) have information on the benthic macroinvertebrate fauna going back to the mid-1980s, allowing an examination of long-term changes in water quality. This analysis combines data from the NC Division of Water Quality (now the Division of Water Resources), the Town of Carrboro and the Town of Chapel Hill. Both sites on Bolin Creek showed a long-term decline in water quality, likely reflecting greater urban land use in Carrboro and Chapel Hill.

Smaller Streams

Current Status. Much better water quality can be found in many of the small streams in Chapel Hill, usually those in older neighborhoods with adequate buffer zones around the stream. Local geology also affects stream classification, with the streams in the slate belt ecoregion usually having the most diverse aquatic communities. Many of these streams go dry during summer droughts, but spring sampling (April) has allowed an evaluation of water quality in these small streams.

> -*Wilson Creek 1* (upstream; not sampled in 2014). Upper Wilson Creek has been rated as either Excellent (2012-2013) or Good (2015). It was not sampled in 2016. It had an increased sediment load in 2015, although the source of nonpoint runoff in this catchment is not clear. This stream also should be investigated to determine the source of nutrient enrichment, as both Wilson Creek sites 1 and 2 have had very abundant growths of filamentous algae.
>
> -*Wilson Creek 2* (downstream). Also in a heavily developed area, but with good buffer zones and good upstream water quality. This is one of the few perennial tributaries. This stream has alternated between a Good-Fair and a Good rating; but it was rated as Excellent in 2015.
>
> -*Wilson Creek 1A* *(between Wilson 1 and 2;* new site in 2016*).* While this site is midway between Wilson 1 and 2, this site appears to have more in common with the generally more stressed downstream site than upstream. This site was collected in summer, rather than spring, so the Biotic Index would be expected to be about 0.2 lower in spring. This would be comparable to Wilson 2 in 2012, which was rated Good.
>
> -*UT Wilson Creek* (new site in 2016). This appears to be another small stream with good habitat and a good buffer zone that seems to be where to find high quality streams in this part of the State.

Streams with Good-Fair, Good or Excellent ratings often were associated with older developments and forested buffer zones. It is encouraging to see that such areas of higher water quality can still be maintained within the city limits. While only two small streams were sampled in 2016, but in previous years, some of the smaller streams showed signs of intermittent flow, i.e. going dry in the summer months. Even in areas where the larger streams have poor water quality, it is useful to look for these pockets of higher ecological value. Urban planners must "think small" and conduct surveys in winter or spring months.

Table 3. Taxa richness and summary parameters, Bolin Creek (sites B4 and B5) and Morgan Creek (site M2), Chapel Hill, North Carolina, 2011-2016.

	March 2011			June 2012			June 2013			June 2014			June 2015			July 2016		
Site:	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	M2*	B4	B5	M2
Ephemeroptera	4	1	7	3	3	6	3	1	3	4	4	9	4	5	8	5	4	8
Plecoptera	1	0	0	1	0	0	0	0	0	1 -	0	0	1	0	1	1	0	0
Trichoptera	3	3	5	4	2	3	3	3	6	5	4	8	7	4	6	5	3	9
Coleoptera	2	0	6	5	3	3	6	3	4	6	2	4	2	3	-	5	7	7
Odonata	2	6	3	3	5	2	1	4	2	6	5	4	5	6	-	4	5	9
Megaloptera	0	0	1	1	0	0	0	0	1	0		0	2	1	-	1	0	
	2																	
Diptera; Misc.	8	6	5	2	2	4	4	2	3	4	3	3	4	4	-	3	4	
	5																	
Diptera: Chironomidae	22	20	23	19	12	13	9	12	21	19	20	16	15	19	-	25	28	21
Oligochaeta	8	6	3	2	2	1	1	4	2	4	6	3	3	2	-	4	3	4
Crustacea	4	2	3	3	1	3	2	1	3	3	1	3	2	1	-	3	1	1
Mollusca	4	4	5	5	0	3	3	2	4	3	1	3	6	2	-	5	4	6
Other	1	2	2	3	0	1	1	2	1	2	2	3	3	1	-	2	3	3
Total Taxa Richness	59	50	63	51	30	39	33	34	50	57	48	58	53	46	-	63	62	75
EPT Taxa Richness	8	4	12	8	5	9	6	4	9	10	8	17	12	9	17*	11	7	17
EPT Abundance	21	26	74	48	34	67	53	40	42	64	48	97	69	47	75	71	54	80
EPT Score	1.6	1	2	1.6	1	1.6	1.4	1	1.6	2	1.6	2.6	2	1.6	2.6	2	1.4	2.6
NC Biotic Index	6.7	7.0	6.7	6.8	6.5	6.3	5.9	6.2	6.6	6.3	6.8	6.1	5.8	5.9	-	6.1	6.4	6.3
BI Score	2	2	2	2	2.4	3	3	3	2	3	2	3	3.4	3	-	3	3	3
Site Score	1.8	1.5	2	1.8	1.7	2.3	2.2	2	1.8	2.5	1.8	2.8	2.7	2.3	-	2.5	2.2	2.8
Rating	Fair	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair	F/G-F	Fair	G-F	G-F	Fair	G-F	F/G-F	Fair	G-F

*4-sample EPT collection; EPT taxa richness count has been corrected to predicted the 10-sample value for easy comparison with the other sites.

Table 4A. Selected intolerant species at larger Chapel Hill streams: Bolin Creek (B4, B5) and Morgan Creek (M1, M2), June 2012-July 2016. Taxa must be Common or Abundant at one or more sites. Yellow highlighting indicates interestingly high numbers of intolerant taxa (suggesting better water quality).

	Jun-12				Jun-13				Jun-14				Jun-15				Jul-16		
Taxon	B4	B5	MI	M2	B4	B5	MI	M2	B4	B5	MI	M2	B4	B5	MI	M2	B4	B5	M2
Leucrocuta aphrodite	-	-	A	-	-	-	A	-	-	-	A	-	-	-	A	-	-	-	-
Isonychia spp	-	-	R	C	-	-	-	-	-	-	A	-	-	-	A	-	-	-	C
Aconeuria abnormis	R	-	C	-	-	-	-	-	R	-	C	-	C	-	A	-	C	-	-
Perlesta sp	-	-	C	-	-	-	A	-	-	-	C	-	-	-	A	R	-	-	-
Chimarra sp	C	A	-	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Neophylax oligius	-	-	-	-	-	-	-	-	-	-	A	R	-	-	A	-	-	-	-
Paraleptophlebia sp	-	-	R	-	-	-	C	-	-	-	-	-	-	-	R	-	-	-	-
Habrophlebia vibrans	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus herricki	C	-	C	C	A	-	A	R	A	R	A	-	A	R	A	R	A	R	-
Elimia sp	-	-	-	-	R	R	-	-	R	-	-	-	A	-	C	-	C	R	-
Sum*	7	10	21	9	22	11	46	11	22	11	56	11	33	11	74	12	26	12	13

Table 4B. Selected intolerant species (Tolerance Value < 3.4) at smaller Chapel Hill streams, July 2016.

Taxon	Wil 1A	UT Wil
Acroneuria abnormis	C	-
Chimarra spp	A	C
Diplectrona modesta	R	A
Lepidostoma	R	A
Neophylax oligius	R	A
Dixa sp	-	R
Anchytarsus bicolor	R	A
Helichus lithophagus	-	C
Optioservus ovalis	R	-
Psephenus herricki	C	C
Elimia sp	R	A
Sum	22	60

*Using Rare = 1, Common = 3, and Abundant = 10.

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Appendix 1. Benthic macroinvertebrates collected from Bolin Creek (B4, B5) and Morgan Creek (M1, M2), Chapel Hill, June 2012-July 2016. R=Rare, C=Common, A=Abundant. Many Morgan Creek collections limited to most intolerant (EPT) groups. Yellow highlights show selected between-year changes.

	Jun-12				Jun-13				Jun-14				Jun-15				Jul-16		
	B4	B5	M1	M2	B4	B5	M1	M2	B4	B5	M1	M2	B4	B5	M1	M2	B4	B5	M2
EPHEMEROPTERA																			
Baetis flavistriga (summer)	A	A	-	A	A	A	C	C	A	A	R	A	A	A	C	A	A	A	C
Baetis intercalaris (summer)	-	R	R	A	-	-	-	-	-	R	-	A	-	-	-	C	R		A
Baetis pluto	-	-	-	-	-	-	-	-	R	-	A	A	-	-	A	A	R	R	A
Acentrella nadineae	-	-	-	R	-	-	-	-	-	-	-	C	-	-	-	R	-	-	R
Acerpenna pygmea	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-
Centroptilum triangulifer	-	-	R	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-	R
Procloeon sp	-	-	-	-	-	-	-	-	-	-	R	R	-	-	-	-	-	-	-
Labiobaetis propinquus	-	-	-	-	-	-	-	-	-	-	C	C	-	R	-	-	-	-	-
Maccaffertium modestum	A	C	A	A	C	-	A	A	A	A	A	A	A	C	A	A	A	A	A
Stenonema femoratum	-	-	C	-	-	-	A	-	-	-	R	-	-	-	R	-	-	-	-
Stenacron interpunctatum	C	-	-	A	A	-	A	C	A	C	A	C	A	R	A	C	A	C	-
Stenacron pallidum	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-
Leucrocuta aphrodite	-	-	A	-	-	-	A	-	-	-	A	-	-	-	A	-	-	-	-
Caenis spp	-	-	-	-	-	-	C	-	-	-	-	A	-	-	-	R	-	-	R
Tricorythodes sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Isonychia spp	-	-	R	C	-	-	-	-	-	-	A	-	-	-	A	-	-	-	C
Paraleptophlebia sp	-	-	R	-	-	-	C	-	-	-	-	-	-	-	R	-	-	-	-
Habrophlebia vibrans	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-
Hexagenia sp	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-
PLECOPTERA																			
Acroneuria abnormis	R	-	C	-	-	-	-	-	R	-	C	-	C	-	A	-	C	-	-
Perlesta sp	-	-	C	-	-	-	A	-	-	-	C	-	-	-	A	R	-	-	-
Neoperla sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Leuctra sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
TRICHOPTERA																			
Cheumatopsyche spp	A	A	A	A	A	A	A	A	A	C	A	A	A	A	A	A	A	A	A
Hydropsyche betteni	A	-	-	A	A	A	R	A	A	A	A	A	A	A	A	A	A	A	A
Chimarra sp	C	A	-	C	A	A	A	C	A	A	A	A	A	A	A	A	A	A	A
Polycentropus sp	-	-	R	-	-	-	-	R	-	-	C	R	-	-	C	R	-	-	C
Phylocentropus sp	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	R	C	-	-
Hydroptila sp	-	-	-	-	-	-	-	-	R	R	-	R	R	-	R	-	-	-	R
Neophylax oligius	-	-	-	-	-	-	-	-	-	-	A	R	-	-	A	-	-	-	-
Pycnopsyche sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Ceraclea transversa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Oecetis sp A	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
Oecetis persimilis	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-
Triaenodes ignitus	-	-	-	-	-	-	-	R	R	-	-	C	R	R	-	A	C	-	C
Nectopsyche exquisita	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	R

	Jun-12			Jun-13			Jun-14			Jun-15		Jul-16		
	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	B4	B5	M2
COLEOPTERA														
Anyronyx variegatus	-	-	-	-	-	-	-	-	-	-	-	-	R	R
Microcyllopus pusillis	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Macronychus glabratus	-	R	-	-	-	-	-	-	-	-	R	C	R	C
Dubiraphia sp	R	-	-	R	R	-	R	-	-	-	-	C	R	C
Stenelmis crenata	A	C	C	C	A	A	A	A	C	C	C	C	A	A
Psephenus herricki	C	-	C	A	-	R	A	R	-	A	R	A	R	-
Helichus spp	R	R	-	R	R	-	R	-	R	-	-	R	-	R
Coptotomus sp	-	-	-	-	-	-	R	-	-	-	-	-	-	-
Neoporus sp	-	-	-	R	-	R	A	-	R	-	-	-	R	R
Neoporus mellitus gr	-	-	R	R	-	R	-	-	R	-	-	-	-	C
Peltodytes sp	R	-	-	-	-	-	-	-	-	-	-	-	-	-
ODONATA														
Argia spp	-	C	A	-	A	A	C	A	A	C	A	R	R	A
Calopteryx sp	-	-	-	-	-	-	-	-	-	-	R	R	R	C
Enallagma spp	-	R	-	R	R	-	C	R	-	-	C	-	R	R
Gomphus sp	-	-	-	-	-	-	R	-	-	-	-	-	-	A
Hagenius brevistylus	-	-	-	-	-	-	R	-	-	R	-	-	-	-
Progomphus obscurus	-	R	R	-	-	-	-	-	-	-	-	-	-	R
Stylogomphus albistylus	-	R	-	-	R	-	R	R	-	R	R	R	C	-
Macromia sp	-	-	-	-	-	-	-	-	R	-	-	-	-	-
Libellula sp	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Pachydiplax longipennis	R	-	-	-	-	R	-	-	-	-	-	-	-	-
Perithemis	-	-	-	-	-	-	-	-	-	-	-	-	-	C
Somatochlora sp	R	R	-	-	-	-	C	A	-	R	R	R	C	R
Boyeria vinosa	-	-	-	-	R	-	-	-	C	C	C	-	-	C
Basiaeshna janata	-	-	-	-	-	-	-	C	R	-	-	-	-	R
MEGALOPTERA														
Sialis sp	R	-	-	-	-	-	-	-	C	R	-	R	-	A
Corydalus cornutus	-	-	-	-	-	C	-	-	C	-	-	-	-	A

	Jun-12			Jun-13			Jun-14			Jun-15		Jul-16		
	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	B4	B5	M2
DIPTERA: MISC.														
Antocha spp	-	-	R	R	-	C	-	-	C	-	R	C	R	C
Tipula spp	C	C	C	C	C	A	C	C	-	C	R	A	C	C
Palpomyia complex	-	-	-	-	-	-	-	-	R	-	-	-	R	R
Simulium spp	A	A	A	A	A	A	A	A	A	A	A	A	A	-
Odontomyia	-	-	-	-	-	-	-	-	-	-	-	-	-	R
DIPTERA: CHIRONOMIDAE														
Ablabesmyia janta/parajanta	R	-	-	-	-	R	-	-	-	C	R	R	-	R
Ablabesmyia mallochi	C	R	R	-	-	R	R	C	C	C	A	R	-	C
Conchapelopia group	R	R	C	C	C	A	R	R	C	C	A	C	R	A
Labrundinia pilosella	-	-	-	-	-	R	-	-	-	-	R	-	-	-
Natarsia spp	R	C	-	-	-	R	-	-	R	-	R	C	A	R
Nilotanypus sp	-	R	-	-	R	-	R	-	R	-	-	-	R	R
Procladius sp	C	-	-	-	-	-	-	-	-	-	R	C	-	R
Cardiocladius sp	-	-	-	-	-	R	-	R	C	-	-	-	-	-
Corynoneura spp	-	-	-	-	R	-	R	R	-	-	-	-	A	-
Thienemaniella spp	R	-	R	-	-	R	-	-	R	-	-	R	A	-
Brillia sp	-	-	-	R	-	R	-	-	-	-	R	-	-	-
Cricotopus annulator	-	-	-	-	-	-	-	-	-	-	-	R	C	-
Cricotopus bicinctus	C	-	R	-	-	-	C	-	-	R	-	A	C	-
Cricotopus cylindraceus	-	-	-	-	-	-	-	-	-	-	-	R	-	-
Cricotopus fugax	-	-	-	-	-	-	-	-	-	-	-	R	R	-
Cricotopus infuscatus	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Cricotopus triannulatus gr	R	-	-	-	R	-	R	-	R	-	-	-	-	-
Eukiefferiella claripennis gr	R	-	-	-	C	-	-	R	-	-	-	-	-	-
Nanocladius spp	-	-	-	-	-	C	-	R	R	-	-	-	-	R
Orthocladius dorenus	-	-	-	-	-	-	-	-	-	-	-	-	R	-
O. (Eud.) dubitatus	-	R	-	-	-	-	R	-	-	-	-	-	-	-
Pagastiella sp	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Parametriocnemus lundbecki	-	R	-	A	A	C	-	C	-	R	R	-	-	-
Rheocricotopus robacki	-	-	-	-	-	R	-	-	-	-	-	C	-	-
Synorthocladius sp	R	-	-	-	-	-	R	R	R	-	-	R	R	-

	Jun-12			Jun-13			Jun-14			Jun-15		Jul-16		
	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	B4	B5	M2
Tvetenia bavarica gr	-	-	-	-	C	-	-	-	-	-	-	-	-	-
Xylotopus par	-	-	-	-	-	-	-	-	-	-	-	R	-	-
Chironomus sp	-	-	-	-	-	-	-	-	R	R	C	-	R	-
Cryptochironomus spp	-	R	R	-	-	R	-	C	R	-	R	R	-	C
Cryptotendipes sp	-	-	R	-	-	-	-	R	-	-	-	-	-	-
Dicrotendipes spp	R	-	C	-	-	R	R	C	-	R	-	C	C	C
Endochironomus nigricans	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Microtendipes spp	-	-	-	C	C	R	C	C	R	C	C	A	C	A
Paratendipes sp	-	R	-	-	R	R	A	C	-	R	C	R	A	-
Phaenopsectra spp	R	C	-	-	-	R	R	A	-	R	C	C	-	-
Phaenopsectra flavipes gr	R	-	-	-	R	-	R	-	-	-	-	-	-	-
Polypedilum flavum	A	A	A	A	C	A	C	-	A	R	-	C	C	A
Polypedilum illinoense gr	-	-	R	-	C	A	-	A	R	-	R	R	R	-
Polypedilum fallax	-	-	-	-	R	-	-	-	-	-	R	-	-	-
Polypedilum scalaenum gr	C	-	R	R	-	-	C	A	-	C	C	R	R	R
Polypedilum halterale gr	-	C	-	-	-	-	-	-	-	-	-	-	-	-
Pseudochironomus sp	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Stenochironomus sp	R	-	-	-	-	R	-	-	-	-	-	-	C	-
Stictochironomus devinctus	-	-	-	-	-	-	-	-	-	-	-	C	-	-
Tribelos sp	C	-	R	R	R	-	C	-	-	A	C	A	A	-
Xenochironomus xenolabis	-	-	-	-	R	-	-	-	R	-	R	-	R	A
Cladotanytarsus sp	-	-	-	-	-	-	-	R	-	-	-	-	-	C
Rheotanytarsus spp	-	-	R	R	-	C	C	C	C	-	-	R	R	C
Paratanytarsus sp	R	-	-	R	-	-	-	C	-	-	-	R	-	-
Tanytarsus spp	C	R	C	-	C	C	-	A	-	R	C	-	C	A
OLIGOCHAETA														
Limnodrilus spp	C	A	-	-	-	R	-	R	-	R	R	C	-	R
Ilyodrilus templetoni	-	-	-	-	-	-	-	R	-	-	-	-	-	-
Allonais	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Nais spp	-	-	-	-	R	-	R	C	R	-	-	-	-	R
Stylaria lacustris	-	-	-	-	R	-	-	-	R	R	-	-	-	-
Slavinia appendiculata	-	-	-	-	-	-	R	R	-	-	-	-	-	-
Ecclipidrilus spp	-	-	-	-	-	-	-	-	R	-	C	-	-	-
Lumbriculus variegatus	-	-	-	C	R	-	R	C	-	C	-	A	A	C
Cambarinicolidae	-	-	-	-	-	-	R	R	-	-	-	-	-	-

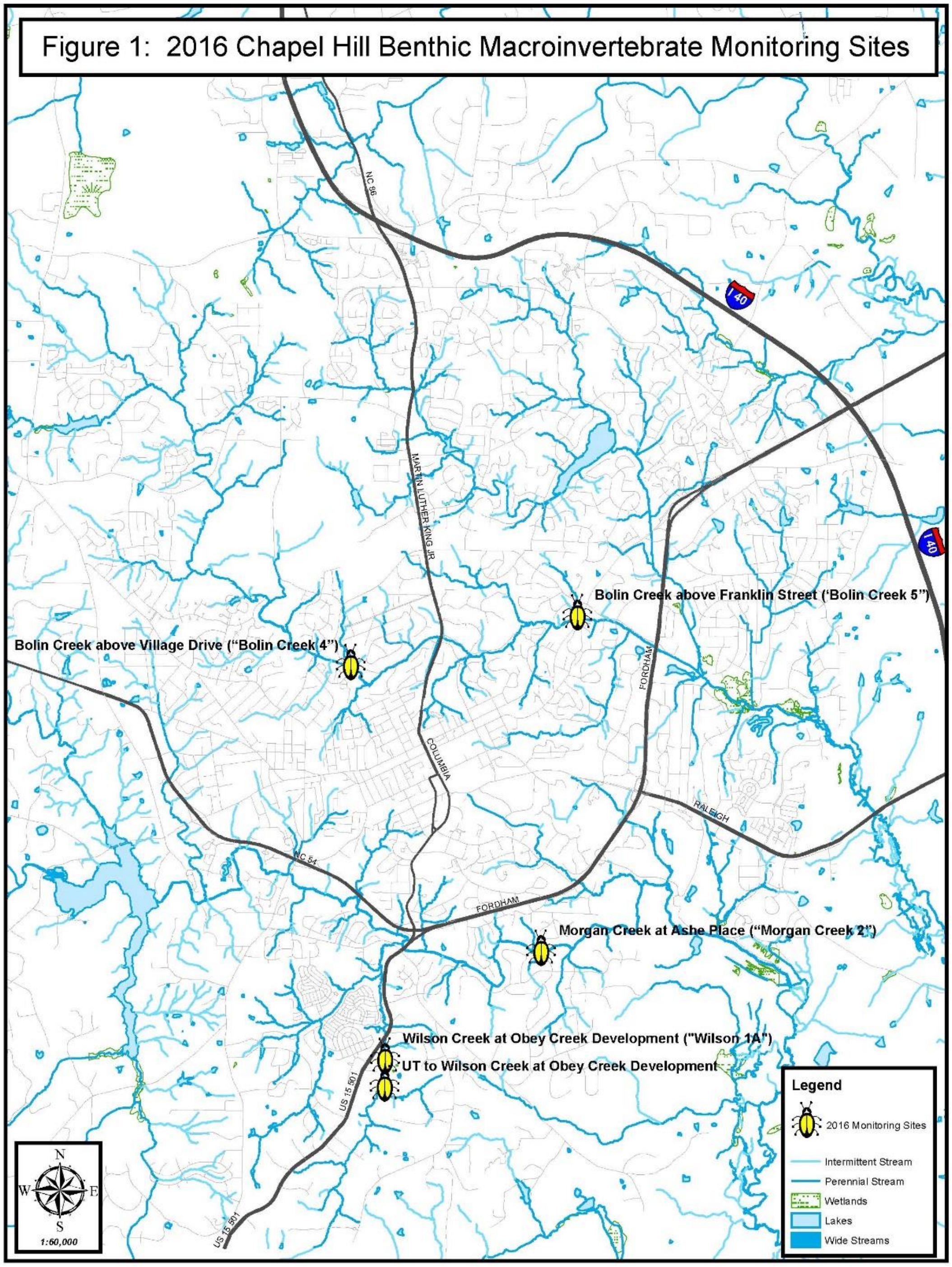
	Jun-12			Jun-13			Jun-14			Jun-15		Jul-16		
	B4	B5	M2	B4	B5	M2	B4	B5	M2	B4	B5	B4	B5	M2
CRUSTACEA														
Crangonyx spp	R	-	R	-	-	-	-	-	-	-	-	-	-	-
Hyallela azteca	A	-	R	R	-	A	C	-	C	R	-	R	-	-
Caecidotea sp	C	-	R	R	-	R	R	-	-	-	-	R	C	-
Cambarus spp	-	A	-	-	C	C	C	C	C	C	C	C	-	A
Procambarus acutus	-	-	-	-	-	-	-	-	R	-	-	-	-	-
MOLLUSCA														
Elimia sp	-	-	-	R	R	-	R	-	-	A	-	C	R	-
Campeloma decisum	R	-	-	-	-	-	-	-	-	-	-	C	-	-
Physa sp	A	-	C	C	-	R	R	C	R	R	R	R	-	R
Stagnicola sp?	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Helisoma anceps	C	-	C	-	-	R	R	-	-	C	-	-	-	R
Menetus dilatus	-	-	-	-	-	-	-	-	-	-	-	C	-	R
Ferrissia sp	-	-	-	R	C	-	-	-	-	R	-	-	R	R
Laevapex fuscus	-	-	-	-	-	R	-	-	C	-	-	-	-	-
Pisidium spp	R	-	-	-	-	-	-	-	-	-	-	-	R	-
Sphaerium	-	-	-	-	-	-	-	-	-	-	-	-	-	A
Corbicula fluminea	A	-	A	-	-	A	-	-	R	-	-	R	R	A
OTHER														
Turbellaria														
Dugesia tigrina	R	-	R	-	-	-	-	R	C	-	-	C	R	R
Cura foremanii	-	-	-	A	R	-	C	R	-	A	-	-	-	-
Hydrolimax grisea	-	-	-	-	-	-	-	-	R	-	-	-	-	-
Hemiptera													-	-
Corixidae	R	-	-	-	-	-	-	-	-	R	-	-	-	-
Ranatra sp	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Hirudinea													-	-
Helobdella triserialis	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Placobdella papillIfera	-	-	-	-	R	-	-	-	-	-	-	-	R	-
Placobdella parasitica	-	-	-	-	-	-	R	-	-	-	-	-	-	-
Neuroptera: Climacia	-	-	-	-	-	-	-	-	C	-	-	-	-	-
Prostoma graecens	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Hydracarina	-	-	-	-	-	-	-	-	-	-	-	R	R	-

Appendix 2. Benthic macroinvertebrates collected at small streams in Chapel Hill, July 2016. R = Rare, C = Common, A = Abundant. Site abbreviations: Wil = Wilson Creek (#1A and UT).

Site:	Wil 1A	UT Wil
Width (m):	2	0.8
EPHEMEROPTERA		
Baetis flavistriga	A	C
Maccaffertium modestum	C	C
Stenacron interpunctatum	R	-
PLECOPTERA		
Acroneuria abnormis	C	-
Eccoptura xanthenes	A	A
TRICHOPTERA		
Cheumatopsyche spp	A	A
Hydropsyche betteni	C	A
Diplectrona modesta	R	A
Chimarra sp	C	C
Neophylax oligius	R	A
Lype diversa	R	-
Lepidostoma sp	R	A
Triaenodes ignitus	-	A
COLEOPTERA		
Stenelmis crenata	R	C
Macronychus glabratus	R	R
Dubiraphia sp	-	R
Optioservus ovalis	R	-
Psephenus herricki	C	C
Ectopria nervosa	-	C
Helichus fastigiatus	A	A
Helichus lithophilus	-	C
Anchytarsus bicolor	R	A
ODONATA		
Calopteryx sp	R	R
Cordulegaster sp	-	R
Stylogomphus albistylus	R	R
Boyeria vinosa	A	C
MEGALOPTERA		
Nigronia serricornis	R	-
DIPTERA: MISC.		
Antocha spp	R	R
Tipula sp	R	R
Hexatoma sp	-	R
Simulium spp	R	C
Dixa sp	-	R
Dolichopodidae	R	-

Site:	Wil 1A	UT Wil
Width (m):	2	0.8
DIPTERA: CHIRONOMIDAE		
Conchapelopia group	R	-
Natarsia sp	C	-
Parametriocnemus lundbecki	-	R
Microtendipes pedellus	R	-
Paralauterborniella nigrohalteralis	-	R
Polypedilum aviceps	R	-
Polypedilum fallax	R	-
Xylotopus par	-	R
OLIGOCHAETA		
Lumbriculus variegata	A	C
Enchytraeidae	-	R
Megadriles	R	-
MOLLUSCA		
Elimia sp	R	A
Physa sp	R	-
OTHER		
Hydracarina	R	-
Dugesia tigrina	-	R
Nematode	-	R

Appendix 3. Map of benthic macroinvertebrate monitoring sites in Chapel Hill, July 2016.



Appendix 4. Chapel Hill Large Stream Sites, July 2016.

Bolin Creek sites are numbered from most upstream (Site 1) to most downstream (Site 5). Sites 1-3 are in Carrboro and are not included in this report. Site 4 was moved from Estes Drive (at the town boundary) to Village Drive in Chapel Hill. Bolin Creek sites are largely in the Slate Belt geologic region and are expected to have a very rocky stream bottom. The lower Bolin Creek site may have characteristics of both ecoregions.

Bolin Creek 4 (Village Drive). This site was moved slightly downstream into Chapel Hill (Village Drive) in 2011, so data from this site could be used by both towns.

Bolin Creek Site 4, July 2016.

This portion of Bolin Creek is similar to the site on Estes Drive, having good rocky substrate. Attached filamentous algae was very abundant at the Village Drive site in March 2011, but was not a problem in 2012-2016. Specific conductance for this site in July 2016, 139 umhos/cm, was similar to 2015, 131 umhos/cm.

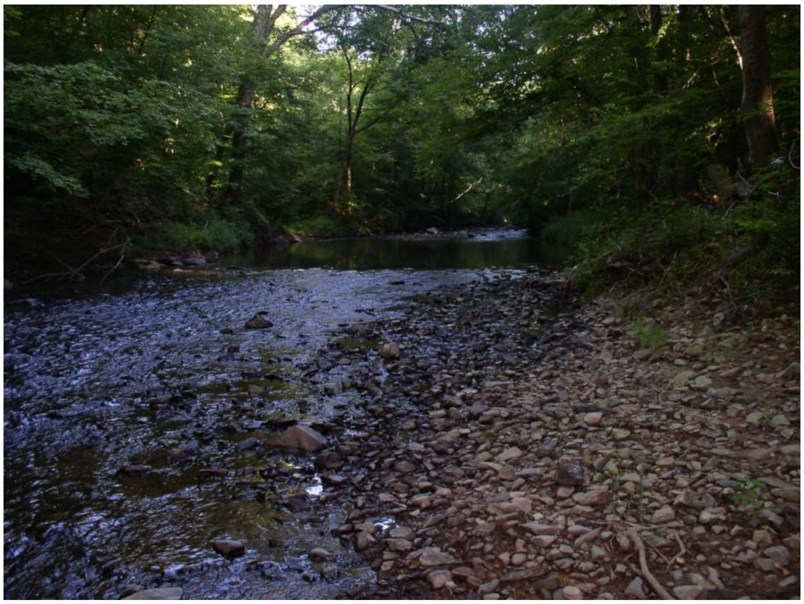
Bolin Creek 5 (Franklin St). Bolin Creek has good rocky substrate near the bridge, but the stream bottom is mostly sand further upstream. A greenway path parallels Bolin Creek in this area.

Bolin Creek Site 5, July 2016

This site drains a heavily developed catchment, including the downtown areas of both Carrboro and Chapel Hill. Specific conductance was much higher at Site 5 than at Site 4 in July 2016: 139 vs. 197 umhos/cm2.

Morgan Creek 2 (Ashe St). This site is located near the NC Botanical Garden and it is downstream of University Lake. Although this part of Morgan Creek is located in a residential area, there is a forested buffer zone along most of the stream.

There was good rocky substrate in the riffles, but pools areas were being filled- in by sand deposition. Flows were very low in 2016, only being visible in the riffles.



Morgan Creek Site 2 (Ashe), July 2016

Appendix 5. Chapel Hill Small Stream Sites, July 2016.

Small streams are grouped into 3 categories, according to local geology. Slate Belt streams are expected to have a very rocky substrate and are located in the western part of Chapel Hill. Triassic streams naturally have a stream bottom of sand and clay and are located in the eastern part of Chapel Hill. Some “Transition” streams share characters of both geologic zones, although the substrate is largely sand and gravel. Within each of these three groups, streams have been sorted by size (as measured by stream width). Slate Belt streams usually have a boulder-rubble substrate, although the more developed areas have sandy pools and/or embedded riffles. Triassic site are largely sand and clay, with a very swampy floodplain. The Transition sites are very sandy, with gravel/rubble riffles. In 2016, Wilson Creek, a transitional stream, was the only small stream sampled.

TRANSITION STREAMS

Wilson Creek 1A (behind Strata Solar). This stream was sampled for the first time in 2016. It is a sandy stream with bank erosion, but prior samples upstream and downstream have indicated good water quality. This section of stream appears to carry a heavy sediment load as evidenced by the half buried tire (photo below).

Wilson Creek behind Strata Solar, July 2016

Wilson Creek behind Strata Solar, Sept 2016

UT Wilson Creek. UT Wilson Creek was sampled for the first time in 2016. The sample was collected at the mouth of a small (130 acres), undeveloped, catchment upstream from Wilson Creek 1A which will be preserved as part of the Obey Creek development.

UT Wilson Creek, July 2016.

Although this stream was very small and very sandy (90% gravel, sand and silt), it supported a surprisingly diverse invertebrate community in 2016.