BIOLOGICAL MONITORING OF BOLIN CREEK CARRBORO, NORTH CAROLINA

April - July 2019

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ATTENTION: PLEASE READ THIS SECTION FIRST

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 our 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. "Benthic" refers to the water and sediments on the bottom of a waterbody. The bottom-dwelling visible insects 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 the ability of the stream to support fishing, swimming and other uses by Carrboro'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", page 2) and "NC Biotic Index" (See page 5). Streams are rated as Excellent, Good, Good-Fair or Fair, using information on the macroinvertebrate community. This report provides information on the present status of water quality in Carrboro's streams and looks for any temporal changes in water quality.

HOW TO READ THIS REPORT

This is the fourth report by Eaton Scientific on water quality and habitat quality in Bolin Creek and its tributaries in Carrboro, North Carolina. This is meant to be, as much as possible, a continuation of the monitoring performed by Lenat Consulting Services for the previous nine years. This report is intended to function as a "stand-alone" document, so it repeats much of the material in earlier reports, especially in the introduction, summary of flow data, methods, and summary of prior biological monitoring. Long lists of species are primarily confined to the appendices, but the reader will often find species names used in the discussion, especially in regard to *tolerant* or *intolerant* species. **To comprehend many of the summary tables, the reader should understand the terms "EPT taxa richness" and "biotic index", and should understand how bioclassifications are assigned to streams** (see Methods section). Once you are familiar with these terms, the fastest way to view our results is in Table 1, Table 4 and the Summary. **Individuals who have read the prior reports may wish to skip to the Results and Discussion sections (Page 11)**.

A companion report has been produced for the Town of Chapel Hill, giving information on lower Bolin Creek, Morgan Creek and several tributary streams. Combining information from these two reports provides valuable information on the effects of urban/residential development in these watersheds. Reports by Eaton Scientific to the town of Chapel Hill can be obtained at: http://www.townofchapelhill.org.

Use their "search" function, entering the word "benthic" and the year of the study. For example, the 2014 Chapel Hill biomonitoring report can be obtained by searching for "benthic 2014".

INTRODUCTION *[Note: this section largely repeated from earlier reports.]*
Water quality in Bolin Creek was evaluated in July 2018 by sampling benthic macroinvertebrates at 4 sites. Benthic macroinvertebrates, especially aquatic insects, are associated with the substrates of streams, rivers and lakes. This group of aquatic species is especially useful as an indicator of biological integrity.

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 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 the number of taxa within the most intolerant groups: Ephemeroptera, Plecoptera and Trichoptera. Higher EPT Taxa richness is associated with good water quality; lower EPT taxa richness is associated with poor water quality.

Bolin Creek Catchment *[Note: this section largely repeated from earlier reports.]*
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. 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 more developed areas in Carrboro and Chapel Hill.

The Carrboro portion of Bolin Creek lies in the Carolina Slate Belt, resulting in the narrow valleys and rocky substrates associated with this geologic zone. Slate Belt streams may have extremely low flows during droughts, as the clay soils have poor groundwater storage (see USGS flow data below). An OWASA (Orange Water and Sewer Authority) sewer easement follows Bolin Creeks for much of its length. Bolin Creek is classified as C NSW (Nutrient Sensitive Waters) upstream of East Franklin Street (US 15-501 Business).

METHODS *[Note: this section largely repeated from earlier reports.]*
All collection methods are derived from techniques used by the NC Division of Water Resources (Lenat 1988). These methods have been in use by DWR biologists since 1982, and have been thoroughly tested for accuracy and repeatability. More details can be found at their web site: http://portal.ncdenr.org/web/wq/ess/bau. Three of DWR's collection methods have been used over the years for the Bolin Creek study: Standard Qualitative (Full scale), Qual-4 and EPT collections. These three methods are briefly described below.

Standard Qualitative Method – Overview [Bolin Creek sites 1-4]

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 kick net 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 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.

EPT Method – Overview [Morgan Creek historic sites]

The EPT method is a more rapid collection technique, limited to 4 samples: 1 kick, 1 bank sweep, 1 leaf pack and visuals. Furthermore, collections are limited to the most intolerant "EPT" groups: Ephemeroptera, Plecoptera and Trichoptera. Note that the EPT method is a subset of the standard qualitative method described above.

Qual-4 Method – Overview [Bolin Creek tributaries]

The Qual-4 method uses the same 4 samples as the EPT method, but all benthic macroinvertebrates are collected. DWR 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 Carrboro 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 NC DWR are Excellent, Good, Good/Fair, Fair and 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 and species richness is the most direct measure of biological diversity. 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 lower and lower species richness. 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. Taxa richness for the most intolerant groups (Ephemeroptera + Plecoptera + Trichoptera, EPT S) is more reliable, but must be adjusted for ecoregion. Piedmont criteria were used for the Bolin Creek study.

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), but with tolerance values derived from NC collections. Biotic indices are based on a 0-10 scale, where 0 represents the best water quality and 10 represents the worst water quality. Abundance values used in the biotic index calculation are 10 for Abundant taxa, 3 for Common taxa, and 1 for Rare taxa. The highest Biotic Index values (>7.5) indicate the worst water quality and receive a score of 1 (Poor); the lowest values indicate Excellent water Quality and receive a score of 5 (see below).

NC Division of Water Quality: Scoring for Biotic Index and EPT taxa richness values for Piedmont streams (Standard Qualitative collections)

Score	BI Values	EPT Values
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 piedmont 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 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 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. NC DWR has developed criteria for small piedmont stream based solely on biotic index values:

Excellent:	<4.3
Good:	4.3-5.1
Good-Fair:	5.2-5.8
Fair:	5.9-6.9
Poor:	>6.9

These criteria were developed only for perennial streams; but many of the Carrboro and Chapel Hill small streams are intermittent.

SAMPLING SITES
The Carrboro section of Bolin Creek has been sampled yearly since 2000. Samples were collected four times a year in 2000 and 2001 to evaluate normal season trends, but only once per year (August or September) from 2003-2007. These samples were collected and identified by Ecological Consultants (Chapel Hill, NC), with assistance from Pennington and Associates (Kentucky). These studies established 4 sites along the Carrboro portion of Bolin Creek, which have been repeated in December 2008 (Lenat Consulting Services, Inc.), July 2009, March 2010 and March 2011, And April-June 2012-2019. The months for sampling in 2012-2015 were selected after consultation with biologists at the NC Division of Water Resources.

Sites are numbered from most upstream (Site 1) to most downstream (Site 4). Note that Site 4 was moved further downstream in 2011, so that data from this site can be used by both Carrboro and Chapel Hill. Bolin Creek was sampled in July 2019. More detailed site descriptions (with photos) are presented in Appendix 2.

Table 1A gives data on habitat ratings and substrate composition at all sites sampled in 2016. The habitat rating is based on standard Division of Water Quality procedures, and produces a value between 0 and 100.

Table 1A. Site characteristics, Carrboro Streams, April and July 2019, Orange County.

Habitat Scoring (0-100) Substrate (%)

Stream	CM	IH	BS	PV	RH	BSV	LP	RVZW	Total	Width	B	R	Gr	Sa	Si	Comments
Morgan Cr NC 54	4	15	12	8	14	5/7	7	5/5	82	8	50	20	10	20	Tr	Mostly Bedrock
Bolin Cr #1	4	13	12	10	14	3/6	10	3/4	79	5	30	40	20	10	Tr	Flow only in riffles
Bolin Cr #2	3	11	11	6	7	3/7	10	4/3	65	5	10	20	20	40	10	More Sand
Bolin Cr #3	5	7	15	8	14	5/5	10	5/5	79	5	60	20	10	Tr	10	Flow only in riffles
Bolin Cr #4	2	15	12	10	12	6/5	10	5/3	80	5	50	30	10	Tr	10	

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

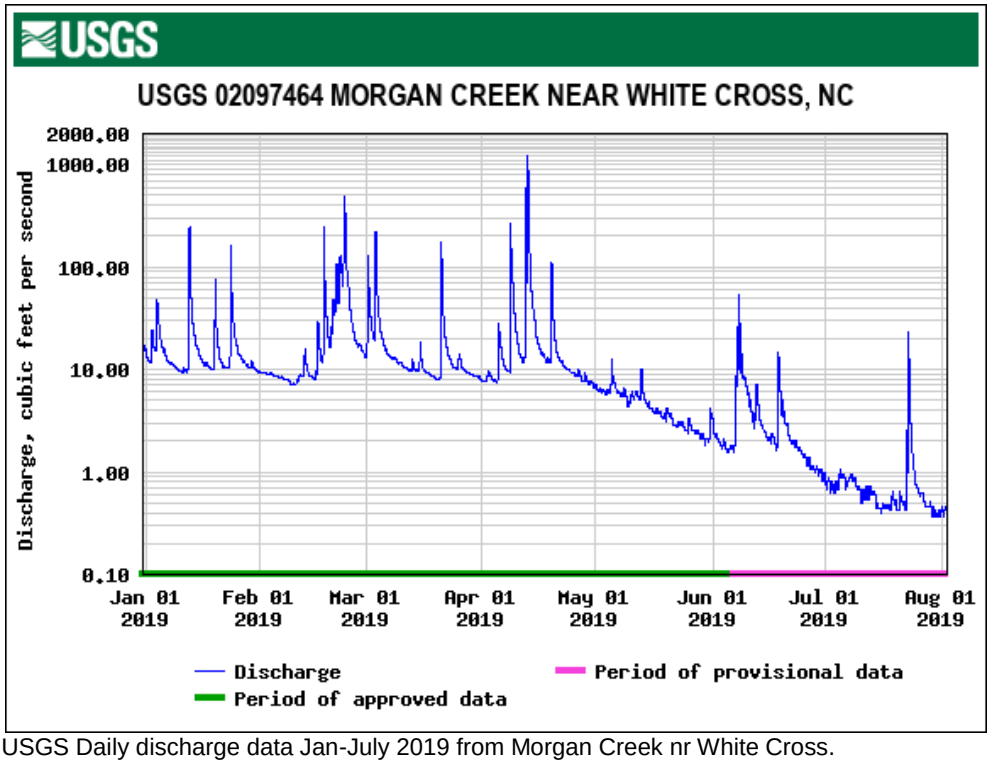
FLOW DATA

The fauna of Carrboro and 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, using data from 2002 to 2018. The USGS measures daily flow at Morgan Creek at NC 54 and Cane Creek; both streams are in Orange County and both are similar in geology to the Bolin Creek catchment, whose gage only has data since 2012. The Cane Creek site, however, may be affected by the upstream Cane Creek Reservoir, so this report only shows the Morgan Creek flow information for long term flows, but also includes Bolin Creek flows for 2019.

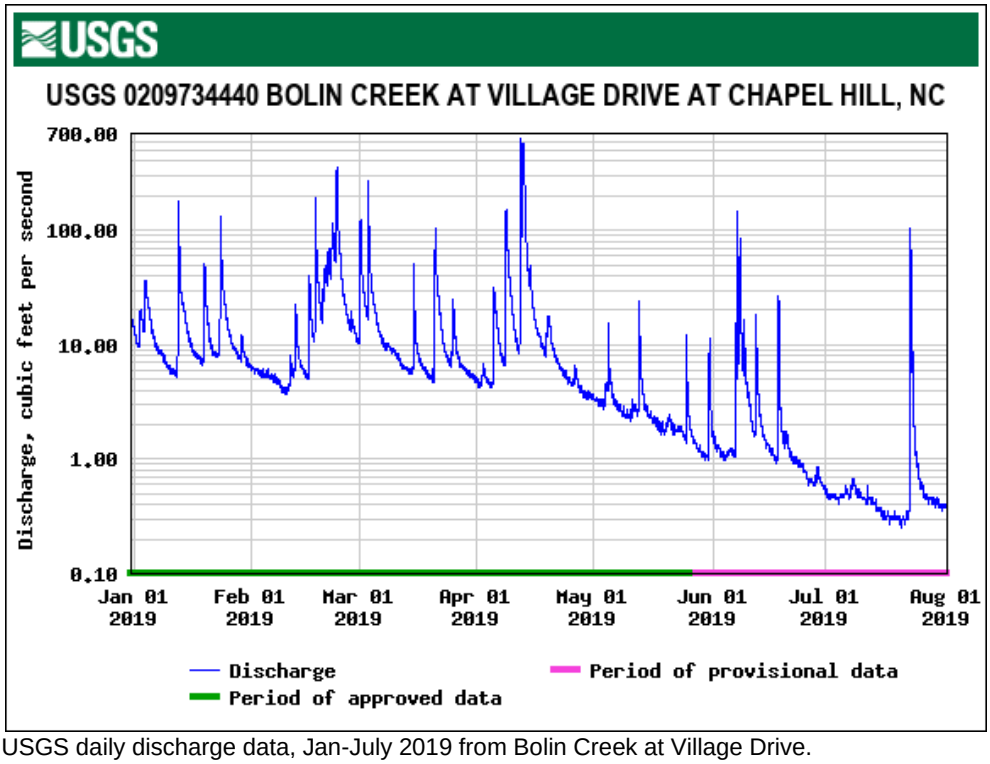
Low flows (less than 0.5 cfs) are highlighted in yellow; severe low flows (less than 0.1 cfs) are highlighted in red**.** Summer flows for 2016-19 were much higher than for 2004-2012; 2013-2019 fall/winter/spring flows were relatively high, especially after Hurricanes Florence and Michael in 2019**.** Monthly mean data is not available for 2019, but the following graph shows daily flows for 2019. This combined data suggests adequate winter and spring flows in the Carrboro/Chapel Hill area since the 2015 collections. Of note are the very high flows following Hurricanes Florence (September – mean flow 30cfs) and Michael (October but November mean flows 36cfs), which were the highest flows in 15 years. Peak maximum flow was on November 12 at over 1000 times base flow.

Mean Monthly flow (cfs) in Upper Morgan Cr (similar to Bolin Creek), 2002-2017.
Morgan Creek nr White Cross (Drainage area 8.3 square miles)

Year	Month: 1	2	3	4	5	6	7	8	9	10	11	12
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	19
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	10	12	44
2016	10	18	14	6.9	6.9	6.3	9	17	2.8	16	1.8	1.5
2017	6.9	3.8	4.4	22	8.2	7.1	1.5	0.6	1.2	0.2	0.7	0.8
2018	5.7	4.9	9.5	11	8.7	2.6	1.1	8.3	30	14	36	16



USGS Daily discharge data Jan-July 2019 from Morgan Creek nr White Cross.



USGS daily discharge data, Jan-July 2019 from Bolin Creek at Village Drive.

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 (1999-2019).

PRIOR BIOLOGICAL DATA *[Largely unchanged from 2018 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 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.

For table below, BI = NC Biotic Index, EPT S = Taxa Richness for the EPT (most intolerant) species, EPT N = EPT Abundance, Bioclass = Bioclassification based on macroinvertebrate data. See Methods for greater detail.

The following data are taken from the Cape Fear River basin report (NC DWR 2003). There have been few recent collections by the NC DWR due to problems with low summer flows.

NC DWR data, 1985-2003. Standard Qualitative and EPT samples.

	Date	Total S	EPT S	BI	BIEPT	Bioclass
Bolin Cr at SR 1777 (#2)	7/01	87	24	5.96	5.18	Good-Fair
	2/01	82	17	6.40	5.23	Not Rated
	4/00	-	26	-	5.05	Good
	3/98	-	23	-	4.22	Good
	4/93	-	24	-	4.46	Good
Bolin Cr at Village Rd (#4)	3/02	40	7	7.00	6.42	Fair (follows Drought)
	7/01	52	9	6.61	6.64	Fair
	2/01	54	6	7.00	5.82	Poor
	2/98	59	26	5.10	3.93	Good
	4/93	-	24	-	3.89	Good-Fair
Bolin Cr at E Franklin St (#5)	7/01	41	4	6.87	6.95	Poor
	3/01	53	4	7.05	5.94	Poor
	3/98	37	13	6.28	6.00	Fair
	2/98	-	4	-	6.65	Poor
	2/93	32	8	6.52	5.34	Fair
	4/86	89	28	6.08	4.34	Good-Fair
Morgan Cr at NC 54	04/18		28			Excellent
	06/13	-	19	-		Good-Fair
	03/09	-	26	-	4.36	Good
	03/08	-	12	-	3.55	Not Rated (Drought)
	06/04	-	18	-	4.43	Good-Fair
	10/03	-	22	-	4.22	Good
	7/03	-	20	-	4.61	Good-Fair
	5/03	-	16	-	4.95	Good-Fair
	3/03	-	12	-	3.07	Not Rated (Drought)
	1/03	-	8	-	3.42	Not Rated (Drought)
	9/02	-	2	-	4.10	Not Rated (Drought)
	4/00	-	36	-	4.21	Excellent
	2/98	80	33	4.37	3.28	Excellent
	10/96	64	22	5.03	4.12	Good
	7/93	61	22	4.92	3.48	Good
	2/93	90	36	4.48	3.23	Excellent
	4/85	109	32	5.71	4.69	Good

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."

Collections from Morgan Creek in 2002 and 2003 were intended to show recovery from the 4- month drought. These data indicated 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.

Town of Carrboro Data, 2000-2007, Ecological Consultants, Standard Qualitative Samples. (DWR method).
Bioclassifications were assigned yearly from 2000-2007, but severe droughts (see flow data) made it inappropriate to assign ratings in 2002, 2006, and 2007. Biotic index numbers are only available from 2000-2001.

	Site:	2 (1777)			3 (Waterside)			4(Estes)		
Date	Parameter:	EPT S	BI	Rating	EPT S	BI	Rating	EPT S	BI	Rating
09/2000		16	6.2	Good-Fair	9	6.1	Fair	4	6.4	Poor
12/2000		18	6.2	Good-Fair	12	6.5	Fair	9	6.0	Fair
03/2001		16	6.4	Good-Fair	10	6.7	Fair	10	6.3	Fair
06/2001		18	-	Good-Fair	16	-	Good-Fair?	11	-	Fair
09/2003		9	-	Fair	7	-	Poor	8	-	Fair
09/2004		11	-	Fair	8	-	Fair	8	-	Fair

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

Morgan Creek, NC 54
Combining the DWR collections (which go back to 1985) with collections for Carrboro gives a good long-term look at changes in water quality for the upper segment of Morgan Creek. Much of the variation in EPT taxa richness observed at this site is due to drought effects and sampling in different months (with higher values for spring collections). However, there does appear to be a decline in water quality, with Excellent ratings found only for years prior to 2000 and more Good- Fair ratings in recent years. Recovery started in 2014-2015, with a Good rating at the site in 2017 and an Excellent rating in 2018, which was mirrored by the DWR Excellent rating this year. A decline to Good in 2019 may be due to scour from high flows from Hurricane Michael, resulting in the loss of bank taxa (primarily Leptocerid caddisflies) and common riffle taxa including the mayfly genus *Baetis* and caddisfly genus *Hydropsyche*.

Bolin Creek (Tables 1-3, Appendix 1)
Early DWR 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) and Estes Drive (#4). It appears that nonpoint source runoff had a significant negative effect on water quality in Bolin Creek between 1998 and 2000 (see "Prior Biological Data" section of this report). Note that changes in habitat were not responsible for any of these 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
-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. A 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

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 have underestimated water quality conditions. Many of the prior invertebrate samples had been collected in September, which would have been the normal seasonal minimum. The repeated Fair and Poor ratings assigned to many Bolin Creek sites during 2000-2004 have been used to suggest that Bolin Creek does not support designated uses. A more complicated pattern, however, has been observed in later collections, with some parts of Bolin Creek receiving a Good-Fair bioclassification. NC Division of Water Resources protocols use an Excellent, Good or Good-Fair rating to show that a site supports designated uses; a Fair rating indicates partial support and a Poor rating indicates nonsupport.

Routine sampling was switched from summer months to winter/spring months in 2008 to avoid these periods of extreme low flow. The most recent collections (2012-2019) were made in both April (tributaries) and in June (Bolin Creek), following DWR recommendations. Much of Bolin Creek is functioning as an intermittent stream during the drought years and this system is difficult to evaluate using DWR criteria for perennial streams.

The EPT taxa richness values for Bolin Creek in 2012-2015 were usually low, but these low values are sometimes offset by the presence of highly intolerant species (for example, see Tables 2 and 3). This pattern suggests that summer low-flows are still limiting the diversity of Bolin Creek macroinvertebrates.

For summaries below, BI = NC Biotic Index, EPT S = Taxa Richness for the EPT (most intolerant) species, EPT N = EPT Abundance, Bioclass = Rating based on macroinvertebrate data.

Data summarized by site for Bolin Creek sites:
-Bolin Creek 1. The most upstream site drains a lightly developed catchment, but we would expect drought effects to be most severe for this segment of Bolin Creek. It has consistently been assigned a Good-Fair bioclassification through 2014, with stable biotic index values of 5.6-6.0. This was the only site that supported "small-stream" species like *Eccoptura xanthenes*. EPT taxa richness was at a minimum in 2013, then rebounded in 2014.

Date	Total S	EPT S	BI	EPT N	Bioclass
7/19	58	11	5.7	60	Good-Fair
7/18	42	9	5.90	42	Fair
7/17	53	7	5.83	47	Fair
4/17	54	13	5.9	54	Fair
7/16	52	7	5.72	31	Good-Fair
6/15	43	10	6.1	59	Fair
4/15	-	11 (13**)	-	33	Fair
6/14	53	11	5.8	78	Good-Fair
4/14	52	13 (15**)	5.6*	93	Good-Fair
6/13	51	8	5.8	58	Good-Fair
6/12	52	10	6.0	57	Good-Fair
3/11	67	18	5.9*	71	Good-Fair
3/10	63	12	5.9*	58	Good-Fair
7/09	54	11	5.5	60	Good-Fair
12/08	57	12	5.9	60	Good-Fair

*Seasonally corrected.
**Corrected for sample type

In 2016, Total taxa richness, Biotic Index and the bioclassification returned to 2014 levels and a Good-Fair rating. The EPT taxa richness, however, declined to the lowest level observed (7). The site was sampled twice in 2017. In the spring, three stonefly taxa were collected, however the abundant mayflies and caddisflies were all tolerant, so the biotic index fell short of a Good Fair rating by 0.05. The summer sample saw a return to record low EPT taxa richness (7) due to the loss of stoneflies and baetid mayflies from the spring sample. The lack of baetid mayflies was startling Since *Baetis flavistriga* was common or abundant at every other site sampled this summer. Usually a lack of baetid mayflies is an indicator of flow problems. Possibly due to increased flows from Hurricane Michael, 2019 marked the return of many taxa, including EPT and other intolerants bringing the bioclassification up to Good-Fair.

-Bolin Creek 2 (SR 1777). This site is only a short distance from Site 1, but drains the Winmore development. Winmore construction started around 2003, and development has continued since that time. Comparison of Site 1 and Site 2 was intended to evaluate the impact of this large development on Bolin Creek. Including information collected by the NC Division of Water Quality, there is information on the benthic macroinvertebrate community going back to 1993, with yearly data from 2000-2019. Comparison of Sites 1 and 2 are limited to 2008-2019.

Bolin Creek 2

Date	Total S	EPT S	BI	EPT N	Bioclass
7/19	78	12	6.04	75	Good-Fair
7/18	67	12	6.07	51	Fair
7/17	74	11	6.23	60	Fair
7/16	60	8	5.9	59	Fair
6/15	43	9	6.1	50	Fair
6/14	54	11	5.9	78	Good-Fair
6/13	37	7	6.0	44	Fair
6/12	42	8	6.4	30	Fair
3/11	52	8	6.8+	32	Fair
3/10	53	13	6.3+	39	Fair
7/09	54	11	6.6	60	Fair
12/08	53	10	5.9	68	Good-Fair
8/06**	47	10	-	50	Fair
9/05**	36	7	-	13	Fair
9/04**	42	10	-	48	Fair
9/03**	35	9	-	40	Fair
7/01*	87	24	6.0	-	Good-Fair
2/01*	82	17	6.5+	-	Not Rated (Drought)
9/00**	71	16	6.2	87	Good-Fair
4/00*	-	26	-	-	Good
3/98*	-	23	-	-	Good
4/93*	-	24	-	-	Good

*DWR data, 1993-2000 collections were limited to EPT taxa
**Early Carrboro data, Ecological Consultants/Pennington,
-No Biotic Index
+Seasonally corrected.

Taxa richness for the most intolerant species (EPT Taxa Richness) was greater than 20 only from 1993 to 2001, with Good ratings only from 1993-2000. A substantial decline in water quality was indicated between 2001 and 2003. This was the time when the Winmore development was started, along with other developments in northern Carrboro. It was also a time of severe summer droughts. To more easily compare Sites 1 and 2, the following table gives between-site changes for all metrics in more recent years. This analysis helps to isolate the effects of Winmore runoff.

Change Bolin Creek 1 vs. Bolin Creek 2 for comparable dates
(Very small changes listed as "0")

Date	Total S	EPT S	BI	EPT N	Bioclass
7/19	20	1	+0.3	15	0
7/18	25	3	+0.2	10	0
7/17	19	4	+0.3	13	0
7/16	8	1	+0.2	28	Good-Fair→Fair
6/15	0	-1	0	-9	0
6/14	0	0	0	0	0
6/13	-14	-1	+0.2	-14	Good-Fair→Fair
6/12	-10	-2	+0.4	27	Good-Fair→Fair
3/11	-15	-10	+0.9	-39	Good-Fair→Fair
3/10	-10	+1	+0.4	-19	Good-Fair→Fair
7/09	-5	0	+1.1	-5	Good-Fair→Fair
12/08	-4	-2	0	-8	0

This table indicates sufficient changes between Sites 1 and 2 to drop the Bioclassification from Good-Fair to Fair from 2009-2013 and again in 2016. The Fair rating assigned to Site 2 from 2003-2006 (prior to sampling at Site 1) suggest this impact also occurred from 2003-2006, an overall period of at least ten years. The 2014, 2015 and 2017-2019 sampling showed little difference between Site 1 and Site 2 for summary metrics, suggesting that current land use above Winmore is having a greater effect than the Winmore runoff.

-Bolin Creek 3. This site has been consistently assigned a Fair rating, with the exception of Good-Fair bioclassifications in 2013 and 2019. Note that the early Carrboro collections (2000-2006) rated the stream based solely on EPT taxa richness. Since this site has an excellent rocky habitat, problems appear to be due to either poor water quality or limited flow.

Date	Total S	EPT S	BI	EPT N	Bioclass
7/19	54	8	5.7	57	Good-Fair
7/18	59	9	6.2	56	Fair
7/17	64	11	6.1	58	Fair
7/16	76	11	6.0	55	Fair
6/15	44	10	6.1	59	Fair
6/14	56	9	6.2	63	Fair
6/13	32	6	5.6	39	Good-Fair
6/12	33	5	5.5	34	Fair
3/11	60	10	6.7*	22	Fair
3/10	32	12	6.3*	60	Fair
7/09	46	10	6.4	64	Fair
12/08	52	12	6.2	63	Fair
8/06**	18	6	-	21	Poor?
9/05**	27	6	-	30	Poor?
9/04**	20	7	-	45	Fair
9/03**	35	9	-	46	Fair
9/00**	48	10	6.1	47	Fair

*Seasonally corrected.
**Early Carrboro data, Ecological Consultants/Pennington.

Bolin Creek 3 is often intermediate between a Fair and a Good-Fair bioclassification: Good or Good-Fair according to the Biotic Index, but Poor or Fair according to EPT taxa richness. When deciding whether to "round-up" or "round-down", DWR criteria employ information on EPT abundance (EPT N). Rounding up (to Good-Fair) is used only when EPT N is greater than a value of 71. EPT N for this site is often 60-64, so only a small change in the benthic community could produce a Good-Fair rating in the future. 2017 is no exception. Even with total taxa collected at this site second only to 2016 and the most EPT taxa since 2010, the EPT N was below average for this site and was thus given a Fair bioclassification.

-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 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 2013-2016 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. In 2016 the rating dropped back to Fair, but only just. The Good-Fair rating would have been maintained if a single additional EPT had been collected and thus should not be viewed as a significant decline in water quality. Declines in taxa richness, EPT taxa richness and EPT abundance in 2017 earned the site a more convincing Fair bioclassification. The Biotic Index improved fractionally from 2016 so these taxa richness declines are not likely a harbinger of decreased water quality

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 2013-2018.

Bolin Creek 4

Date	Total S	EPT S	BI	EPT N	Bioclass
7/19	62	10	6.2	68	Fair
7/18	60	8	6.0	73	Fair
7/17	37	8	6.0	57	Fair
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

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

Indicator species at Bolin Creek sites

Appendix 3A shows the changes in abundance for 2 key indicator groups of intolerant taxa: a philopotamid caddisfly (*Chimarra*), and two perlid stoneflies (*Acroneuria abnormis/Eccoptura xanthenes*). *Acroneuria* had almost disappeared from Bolin Creek in 2009-2011, with only a single specimen collected in 2011. Although this intolerant species was abundant at Bolin Creek 3 in 2012, it was absent or rare at Bolin Creek sites in 2013 and 2014. The slight increase in abundance for this species at Bolin 4 in 2015, at Bolin 3 in 2016 and an additional increase to Abundant at Bolin 4 in 2018 is a very positive sign. It is unclear why no stoneflies, including *Acroneuria* or *Eccoptura*, were collected at any of these Bolin creek sites in 2019, a year when bioclassifications improved.

Chimarra had shown a significant decline in 2011 and 2012, being abundant only at the upstream site on Bolin Creek. With the exception of 2018, when *Chimarra* was Common at all sites, most sites have seen abundant *Chimarra* since 2013. The latter pattern suggested that the better flow conditions allowed more recovery to occur in Bolin Creek.

A more extensive list of selected intolerant species is presented in Appendix 3B, producing a score (the "Sum" line) that is useful in comparing Bolin Creek sites. This score had shown a consistent decline below the Winmore development (Site 1 vs. Site 2), associated with runoff and sediment deposition. This between-site difference, however, was reduced in 2014-2015. A decline for the intolerant sum at Bolin 1 between 2014 (43) and 2015 (22) and staying low in subsequent years (21), is further evidence of recent water quality problems upstream of Bolin Creek Site 1. Figures 1 and 2 are a graphical summary of the data shown in these appendices that more clearly shows the declining water quality from Bolin Cr 1 affecting the water quality in Bolin Cr 2. Bolin Cr 3 is surprisingly stable, while Bolin Cr 4 showed some signs of possible recovery until 2019,when the number of selected intolerant taxa dropped by over 50%.

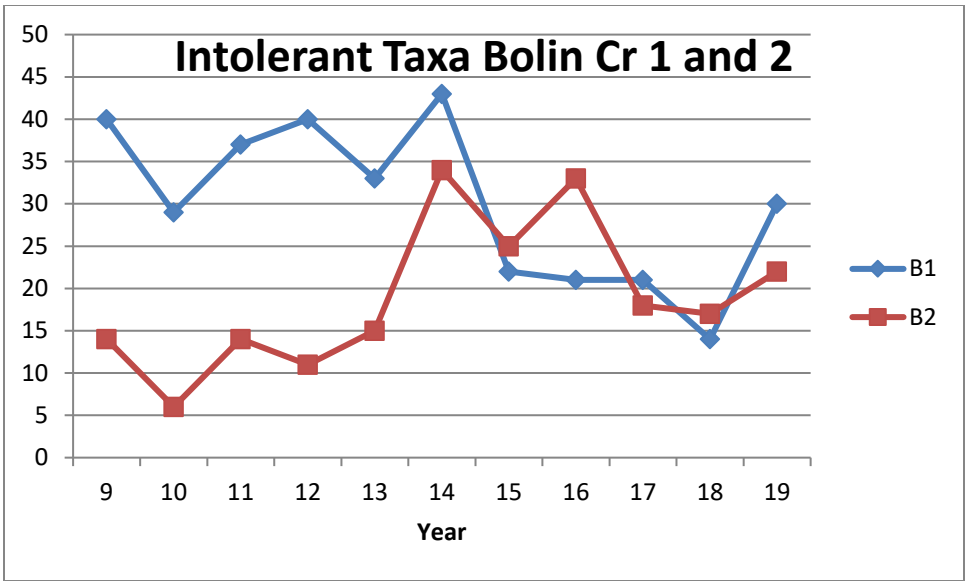


Figure 1.Intolerant taxa richness Bolin Cr 1 and Bolin Cr 2, 2009-2019.

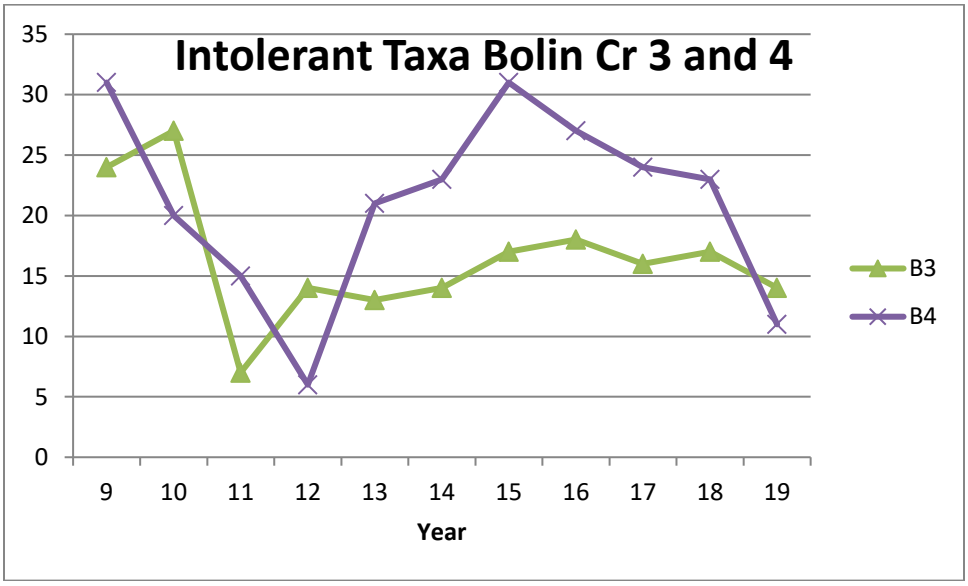


Figure 2. Intolerant taxa richness Bolin Cr 3 and 4, 2009-2019

None of the Carrboro Bolin Creek sites had a community that would indicate organic loading. Some sites, however, had fauna (especially the snail *Physa*) that suggested low dissolved oxygen concentrations. *Physa* was abundant at Bolin Creek sites 2 and 4 in 2011; both of these sites had very high levels of filamentous algae. Such high levels of algae can cause super-saturation during the day, but low dissolved oxygen levels at night. This pattern was observed in 2012 only at Bolin Creek 4 and abundant growth of filamentous algae was not observed for any Bolin Creek site. In 2013, *Physa* was abundant at sites 1 and 2, suggesting some dissolved oxygen problems in the headwater area. Under the higher flow conditions of 2014-2016, *Physa* was neither Common nor Abundant at any of the Bolin Creek sites since.

Bolin Creek Tributaries

Although much of Bolin Creek shows some water quality problems, some tributary sites still maintain Good or Excellent bioclassifications. Summary information is given below for all tributaries sampled since 2009. No tributaries were sampled in 2019.

-UT at Horne Hollow Rd. Received Excellent bioclassifications in 2011 and 2012, however only rated Good-Fair in 2017

-Jones Creek at Turtle back Crossing. Sampled in 2012 and tentatively assigned a Fair rating. There are some intolerant species in this segment of Jones Creek (2 stoneflies), but other taxa suggest both low dissolved oxygen (*Physa*) and organic loading (*Ilyodrilus templetoni, Limnodrilus sp.*).

-UT Tanyard Branch below Baldwin Park. This site was sampled in 2009 and 2012. Although both collections produced a Poor rating, total taxa richness increased from only 12 in 2009 to 16-21 in the last two collections. EPT taxa richness increased from 2 in 2009 to 4 in 2012.

-UT Bolin Creek at Estes Drive Extension. This very small stream was sampled prior to a mitigation project. The very limited fauna clearly indicates Poor water quality. The abundance of the air-breathing snail, *Physa*, suggested some problems with low dissolved oxygen.

-UT Bolin at Seawell School Road. Sampled in 2009, 2011, 2012, 2014 and 2017. Collections from all years indicated an area of Good-Excellent water quality, with many highly intolerant species not observed in other Carrboro collections (*Wormaldia, Psilotreta, Neophylax ornatus, Rhyacophila glaberrima*).

-Jolly Branch. Jolly Branch is located near the Carrboro/Chapel Hill boundary. The lack of some expected species in most years (for example heptagenid mayflies and hydropsychid caddisflies) clearly indicated stream flow has often been intermittent. Abundant EPT species in most years included two intolerant stoneflies *(Perlesta, Amphinemura*) and one intolerant caddisfly (*Rhyacophila fenestra*), indicating no significant water quality problems. The stoneflies were less abundant in 2014, but this may be due to colder water temperatures and delayed development of these species. This site was tentatively given a Good-Fair rating in all years, but appeared to have the best water quality in 2013-2014

-Dry Gulch. Dry Gulch drains a largely residential area, with a “Low Impact Development” (LID) adjacent to the sampling location. There have been some restoration activities in this area, including stream bank stabilization. The abundance of *Ironoquia puntatissima* in 2014 indicated that this is an intermittent stream, but the abundance of the intolerant caddisfly *Chimarra* suggested some improvement in water quality. Few invertebrates were found in the stream above the development, but macroinvertebrates became abundant about 30 meters further downstream. This may indicate further groundwater inputs to the stream. Between 2009 and 2014, we observed an increase in EPT taxa richness and a change to more intolerant species. The overall classification changed from Poor in 2009 to Fair in 2014.

-UT Bolin Creek at Camden Rd. This site was sampled for the first time in 2012 and was assigned a Fair rating using small stream Biotic index criteria. Data from 2015 was very similar, although with slightly higher EPT taxa richness (2015:8, 2012: 5). Note that the biotic index values (6.1-6.2) are within the Good-Fair range for permanent streams. One highly intolerant species was abundant (*Neophylax oligius*), suggesting that a Good-Fair rating is appropriate. However, the abundance of the tolerant midge, *Chironomus*, suggested accumulation of organic matter in a slower section of the stream.

-UT Bolin Creek near the Power Line (upstream of Bolin Creek 1). This small stream received a Good-Fair rating. Several intolerant species were recorded at this site, including *Baetis pluto*, *Amphinemura*, two species of *Neophylax* and two species of *Rhyacophila*.

-Toms Branch at Poplar Dr. Was sampled for the first time in 2017. A lack of flow seems to be the biggest problem in this stream as evidenced by the near lack of filter feeders – animals that require flow to bring them food. The presence of three intolerant taxa in the one small area of flow suggests there may be limited pollutants, however piles of grass clippings below the riffle can’t be helping the low oxygen issues here.

-UT Bolin Cr off Reynard Rd. This UT flows into Bolin Creek above the Winmore Rd site. A sewer line was being laid beside the stream at the time of sampling. Though there were long stretches of stream without flow, there were sufficient riffles present to support several different intolerant taxa and earn the stream a Good-Fair bioclassification.

SUMMARY

Biological sampling on Bolin Creek had consistently indicated Good-Fair water quality through 2014 in upper Bolin Creek (Site 1), in spite of some development and persistent summer droughts. In 2015, however, this site declined to Fair for both the April and June collections, suggesting a water quality problem in the Bolin Creek headwaters. The causes of this problem have not yet been identified. While the bioclassification returned to Good-Fair in 2016, by 2017, both spring and summer samples slipped just barely to a Fair bioclassification which continued through 2018. Site 2 (below the Winmore development) was assigned only a Fair rating for 2010-2013, although there is some evidence of a gradual recovery for this part of the stream in 2012 and 2013. Both sites were assigned a Good-Fair rating in 2014, indicating further improvement. In 2016 - 2018, water quality problems returned with a Fair bioclassification. Water quality improvement in 2019, from Fair to Good-Fair at sites 1, 2 and 3 seemed to be correlated with higher flows

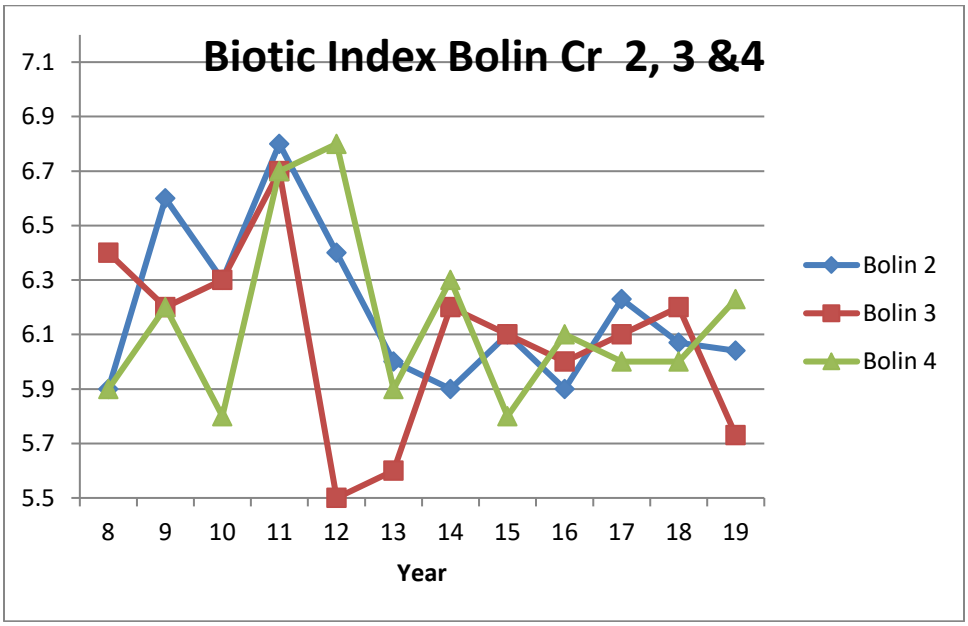


Figure 3. Biotic Index over time for Bolin sites 2, 3 & 4.

Figure 3 is a summary of the Biotic Index at the lower three Bolin Creek sites since 2008. There appears to be a wide variety of Biotic Index values during the very low flow/drought years of 2008-2012.Since the series of drought years ended, these areas further downstream are usually rated as Fair, with Biotic Index values confined to a fairly narrow range of 5.8-6.3. Both Sites 3 and 4 are intermediate between a Fair and a Good-Fair rating, and would be assigned Good-Fair ratings based solely on Biotic Index values. A very small improvement, in the case of Site 4 a single additional EPT, might bring both sites up to a level that indicates they are “sustaining designated uses”.

The 2017 collections indicate a slight slippage of water quality in the headwater area, and stable water quality in Bolin Creek near the Carrboro/Chapel Hill boundary which continued in 2018. This trend reversed in 2019 when sites 1-3 received Good-Fair ratings. Site 3 in particular showed a marked decline in Biotic Index to levels not seen since 2013. The major difference between 2019 and previous years appears to be the extended high waters since Hurricanes Florence and Michael perhaps providing flow to a stream segment that chronically exhibits low flow.

No sites had indications of organic loading problems, but some sites on Bolin Creek have shown symptoms of low dissolved oxygen in 2011 and 2013. This problem was not observed in 2014 - 2019, possibly due to higher flows.

Although much of Bolin Creek has water-quality problems, tributary sites may support more intolerant aquatic communities. Studies in both Carrboro and Chapel Hill have shown that Good- Excellent water quality may be found in smaller streams, especially in residential areas with large lot sizes and good riparian buffer zones. Such small streams, however, may have intermittent flow and must be sampled in winter or spring.

Table 1. Taxa richness** by group and summary parameters, Bolin Creek and Morgan Creek, Orange County, 2000-2019.

Winter/ Early Spring collections

Date:	12/08					03/10					03/11				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Total Taxa Richness	-	57	53	52	44	-	63	53	32	42	-	67	52	60	58
EPT Taxa Richness	21*	12	10	12	12	24*	12	13	12	9	21*	18	8	10	8
EPT Abundance	88	60	68	63	63	112	58	39	60	35	6	71	32	22	21
NC Biotic Index	-	5.9	5.9	6.2	5.9	-	5.7	6.1	6.1	5.8	-	5.7	6.6	6.5	6.7
Rating	G?	G-F	G-F	F	F	G	G-F	F	F	F	G?	G-F	F	F	F

June Collections

Date:	06/12					06/13					06/14					
Site:	M	1	2	3	4	M	1	2	3	4	M	1+	1	2	3	4
Ephemeroptera	7	3	3	3	3	11	3	3	3	3	10	4	5	6	5	4
Plecoptera	2	2	-	1	1	1	1	0	0	0	2	1	-	-	1	1
Trichoptera	2	5	5	1	4	5	4	4	3	3	5	8	6	5	3	5
Total Taxa Richness	-	52	42	33	52	51	37	32	33	-	52	53	54	56	57	
EPT Taxa Richness	13*	10	8	5	8	19*	8	7	6	6	20*	15*	11	11	9	10
EPT Abundance	44	57	30	34	48	89	58	44	39	53	106	93	78	78	63	64
NC Biotic Index	-	6.0	6.4	5.5	6.8	-	5.8	6.0	5.6	5.9	-	5.4	5.8	5.9	6.2	6.3
Rating	G-F?	G-F	F	F	F	G-F	G-F	F	G-F	F	G-F	G-F	G-F	G-F	F	F

Date:	06/15						7/16				7/17				
Site:	M	1+	1	2	3	4	1	2	3	4	M	1	2	3	4
Ephemeroptera	8	6	5	5	5	4	3	3	4	5	13	3	4	4	3
Plecoptera	4	2	1	0	0	1	0	0	1	1	5	0	0	1	1
Trichoptera	7	3	4	4	5	7	4	5	6	5	11	4	7	6	4
Coleoptera			5	4	3	2	5	9	6	5		6	7	5	4
Odonata			5	6	6	5	7	8	8	4		7	7	6	5
Megaloptera			0	1	0	1	1	0	1	1		1	2	1	0
Diptera: Misc.			4	3	3	4	3	5	3	3		2	3	2	3
Diptera: Chironomidae			10	16	13	15	15	15	30	25		19	27	27	10
Oligochaeta			1	2	1	3	4	3	4	4		3	2	3	2
Crustacea			1	2	4	2	1	1	3	3		1	2	2	1
Mollusca			5	6	4	6	7	7	7	5		4	8	5	2
Other			2	1	0	3	2	4	3	2		3	5	2	2
Total Taxa Richness	-	-	43	43	44	53	52	60	76	63	-	54	74	64	37
EPT Taxa Richness	22*	13*	10	9	10	12	7	8	11	11	29	7	11	11	8
EPT Abundance	112	33	59	50	59	69	31	59	55	71	143	47	60	58	57
NC Biotic Index	-	-	6.1	6.1	6.1	5.8	5.7	5.9	6.0	6.1	4.9	5.8	6.2	6.1	6.0
EPT Score	3	2	2	1.6	2	2	1.4	1.6	2	2	-	1.4	2	2	1.6
BI Score	-	-	3	3	3	3.4	4	3	3	3	4	3.4	3	3	3
Site Score	3	2	2.5	2.3	2.5	2.7	2.7	2.3	2.5	2.5	4	2.4	2.5	2.5	2.3
Rating	G-F	F	F	F	F	G-F	G-F	F	F	F	G	F	F	F	F

Date:	18-Jul					19-Jul				
Site:	M	1	2	3	4	M	1	2	3	4
Ephemeroptera	13	2	5	4	3	8	6	5	3	4
Plecoptera	6	0	0	1	1	7	0	0	0	0
Trichoptera	12	7	7	4	4	9	5	7	5	6
Coleoptera		6	8	8	5		6	8	7	6
Odonata		6	6	8	4		4	9	5	3
Megaloptera		1	1	2	0		1	1	1	1
Diptera: Misc.		1	5	3	4		1	4	5	4
Diptera: Chironomidae		10	19	19	27		20	29	19	29
Oligochaeta		0	2	2	2		3	2	2	1
Crustacea		1	2	2	1		2	1	1	1
Mollusca		5	8	4	7		6	8	3	4
Other		3	4	2	2		4	4	3	3
Total Taxa Richness		42	67	59	60		58	78	54	62
EPT Taxa Richness	32	9	12	9	8	24	11	12	8	10
EPT Abundance	129	42	51	56	73	94	60	75	57	68
NC Biotic Index		5.9	6.1	6.2	6		5.7	6.04	5.7	6.2
EPT Score	5	1.6	2	1.6	1.6	4	2	2	1.6	2
BI Score		3	3	3	3		4	3	4	3
Site Score	5	2.3	2.5	2.3	2.3	4	3	2.5	2.8	2.5
Rating	Ex	F	F	F	F	G	G-F	G-F	G-F	F

(G= Good, G-F = Good-Fair, F = Fair)

*Value predicted for the more comprehensive standard 10-sample collection (Conversion by x 1.15)
**Taxa richness is a count of the number of different kinds of organisms; “EPT” refers to the group of most intolerant species (Ephemeroptera. Plecoptera and Trichoptera).
+A spring (April) collection to evaluation seasonality in the headwaters

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Appendix 1. Bolin Creek, Sites 1-4, June 2013-2019. R=Rare, C=Common, A=Abundant, Morgan Creek collections (NC 54) limited to the most intolerant (EPT) groups.

Date:	06/13					06/14					06/15					07/16				07/17					07/18					7/19				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
EPHEMEROPTERA																																		
Maccaffertium modestum	A	A	A	A	C	A	A	A	A	A	A	C	A	A	A	R	C	A	A	A	A	A	A	A	R	A	A	A	A	C	A	A	A	A
Stenonema femoratum	A	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenacron interpunctatum	A	A	A	C	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	C	A	A	A	C	R	A	A	A	A	-	A	A	C	C
Stenacron pallidum	R	-	-	-	-	-	C	C	R	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	C	-	-	-	-	-	-	-	-	-
Leucrocuta aphrodite	A	-	-	-	-	A	-	-	-	-	A	-	-	-	-	-	-	-	-	A	-	-	-	-	A	-	-	-	-	A	-	-	-	-
Baetis flavistriga	C	A	A	C	A	R	A	C	A	A	C	A	C	C	A	-	A	C	A	A	-	C	R	A	A	-	C	R	A	-	C	A	C	A
Baetis intercalaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-
Baetis pluto	-	-	-	-	-	A	C	A	R	R	A	R	R	C	-	R	-	R	R	A	-	R	R	-	A	-	R	-	-	-	-	R	-	-
Labiobaetis propinquum	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centroptilum triangulifer	-	-	-	-	-	R	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diphetor hageni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Heterocloean amplum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	A	-	-	-	-	A	-	-	-	-
Procloeon sp	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Acerpenna pygmaea	-	-	-	-	-	-	-	R	-	-	-	R	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Caenis spp	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	R	-	-	-	A	-	R	C	-	C	R	-	-	C
Isonychia spp	-	-	-	-	-	A	-	-	-	-	A	-	R	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paraleptophlebia sp	C	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Habrophlebia vibrans	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Danella simplex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Ephemerlla dorothea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Erylophella enoensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Erylophella verisimilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	A	-	-	-	-	A	-	-	-	-
Hexagenia sp	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plauditus dubius gr*	R	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	R	-	-	-	-
PLECOPTERA																																		
Acroneuria abnormis	-	-	-	-	-	C	-	-	R	R	A	-	-	-	C	-	-	R	C	A	-	-	R	R	A	-	-	C	A	A	-	-	-	-
Neoperla sp	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eccoptura xanthenes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	R	-	-	-	-	C	-	-	-	-
Perlesta sp	A	R	-	-	-	C	-	-	-	-	A	C	-	-	-	-	-	-	-	A	-	-	-	-	R	-	-	-	-	C	-	-	-	-
Clioperla clio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Isoperla kerchneri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-	-	C	-	-	-	-	A	-	-	-	-
Amphinemoura sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	R	-	-	-	-	A	-	-	-	-
Leuctra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
TRICHOPTERA																																		
Cheumatopsyche spp	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	C	A	R	A	C	A	A	C	A	A	A	A
Hydropsyche betteni	R	R	R	C	A	A	A	A	A	A	A	A	C	A	A	C	A	A	A	A	C	A	A	A	R	C	C	A	A	-	A	A	A	A
Diplectrona modesta -	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chimarra sp	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	R	A	A	R	C	-	C	A	C	A	A	A	A
Lype diversa	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-

Date:	06/13					06/14					06/15					07/16				7/17					07/18					07/19				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Nyctiophylax sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Polycentropus sp	-	-	-	-	-	C	-	-	-	-	C	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	R	-	-	-	R
Phylocentropus sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triaenodes ignitus	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	R	C	C	C	R	C	A	A	C	-	C	A	C	C	-	C	A	A	A
Triaenodes marginatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-
Mystacides sepulchralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	C	-	-	-	-	-	-	-
Nectopsyche exquisita	-	-	-	-	-	-	-	R	-	-	-	-	R	R	R	-	-	-	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-
Oecetis sp	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-	-	R	-	-	-	-	R	R	R
Ceraclea sp	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	R	-	-	-	-	C	-	-	-	-	C	-	-	-	-
Lepidostoma sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	R	-	-	-	-	R	-	-	-	-
Hydroptila sp	-	-	-	-	-	-	-	-	-	R	R	-	-	-	R	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Neophylax atlanta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	R	-	-	-	-
Neophylax oligius	-	R	C	C	-	-	A	A	A	-	-	A	-	-	-	-	-	C	-R	-	R	-	C	-	-	R	-	C	-	-	-	C	-	-
Pycnopsyche sp	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Rhacophila glaberrima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Rhyacophila fenestra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	C	-	-	-	-	C	-	-	-	-
Anisocentropus pyraloides	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psilotreta spp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
COLEOPTERA																																		
Anchytarsus bicolor		R	R	-	-		C	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Ancyronyx variagatus		-	-	-	-		-	-	-	-		-	-	-	-	R	R	C	-	-	C	R	C	-		-	R	C	-		-	C	R	R
Macronychus glabratus		-	-	-	-		-	-	R	-		-	-	-	-	-	-	-	C	-	R	R	R	-		R	R	R	R		R	-	R	R
Dubiraphia sp		C	-	-	R		R	R	C	R		-	R	R	-	-	C	A	C	-	-	C	-	R		C	C	C	R		R	C	C	R
Microcyoelopus sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	R	-		-	-	-	R
Oulimnius sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	R	-	-	-	-		-	-	-	-		-	-	-	-
Stenelmis sp		A	C	C	C		A	A	C	A		C	A	R	C	C	A	A	C	C	C	A	C	C		C	A	C	R		A	A	C	C
Psephenus herricki		A	R	C	A		A	R	R	A		R	C	R	A	-	A	A	A	A	R	C	R	A		R	C	R	-		A	A	R	-
Helichus spp		A	A	-	R		C	C	R	R		R	C	-	-	C	R	R	R	C	-	A	C	-		C	A	C	R		R	C	R	R
Coptotomus sp -		-	-	-	-		-	-	-	R		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Neoporus spp		C	C	-	R		-	-	-	A		C	-	-	-	R	R	-	-	C	C	-	-	R		-	R	R	-		-	A	C	-
Neoporus mellitus gr		A	-	-	R		-	R	-	-		R	-	-	-	C	C	C	-	-	C	R	-	-		R	C	-	R		A	-	-	-
Peltodytes sp		-	-	-	-		-	-	-	-		-	-	-	-	-	C	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Haliplus sp		-	-	-	-		-	-	-	-		-	-	-	-	-	C	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
ODONATA																																		
Argia spp		-	-	-	-		A	C	C	C		C	R	R	C	C	R	-	R	-	C	C	R	C		C	-	R	-		C	R	R	-
Calopteryx sp		-	-	-	-		R	-	R	-		-	R	-	-	R	C	C	R	C	C	A	-	C		R	A	R	-		-	C	-	R
Enallagma spp		-	-	-	R		R	C	R	C		-	-	R	-	R	C	C	-	R	R	R	C	-		R	C	C	R		-	C	R	-
Ischnura sp		-	R	-	-		-	R	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	C	-	-
Hagenius brevistylus		-	-	-	-		-	-	-	R		-	-	-	R	-	-	-	-	-	-	-	-	R		-	-	R	R		-	-	-	-
Gomphus sp		-	-	-	-		-	R	-	R		R	-	R	-	C	C	R	-	C	A	C	R	-		-	C	R	-		R	R	-	-
Stylogomphus albistylus		R	R	R	-		-	R	-	R		A	A	C	R	C	A	R	R	-	C	C	R	-		C	C	R	-		C	A	R	R
Progomphus obscurus		-	-	-	-		-	-	-	-		-	R	-	-	-	C	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Somatochlora sp		R	C	-	-		C	A	C	C		R	C	C	R	R	-	R	C	R	R	C	-	R		C	C	C	C		-	C	R	-

Date:	06/13					06/14					06/15					07/16				07/17					07/18					07/19				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Boyeria vinosa		R	-	-	-		-	R	-	-		C	C	C	C	A	A	C	-	-	C	A	C	C		-	C	R	-		A	A	C	A
Basiaeschna janata		-	-	-	-		C	R	R	-		-	-	-	-	-	C	R	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Macromia sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	R	-	-	-	-	-	-		-	-	-	-		-	C	-	-
MEGALOPTERA																																		
Chauliodes pectinicornis		-	-	-	-		-	-	-	-		-	-	-	-	R	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Corydalus cornutus		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	R	-	-		-	-	R	-		-	-	-	R
Nigronia serricornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-		-	-	-	-		-	-	-	-
Sialis sp		-	-	-	-		R	-	R	-		-	R	-	R	-	-	C	R	-	R	R	R	-		C	C	C	-		R	R	R	-
DIPTERA: MISC.																																		
Antocha spp		-	-	-	R		-	-	-	-		-	-	-	-	-	-	C	C	-	-	R	-	R		-	-	R	R		-	R	C	A
Polymeda/Ormosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-		-	-	-	-		-	-	-	-
Tipula spp		R	R	C	C		A	C	C	C		A	A	R	C	C	C	C	A	-	-	A	R	C		R	C	R	C		-	A	R	A
Pseudolimnephila sp		-	-	-	-		-	-	-	-		-	-	-	-		-	-	-		-	-	-	-		-	R	-	-		-	-	-	-
Limonia sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Chrysops sp		-	-	-	-		-	-	-	-		-	-	-	-	R	R	-	-	-	-	-	-	-		-	C	-	-		-	-	-	-
Palpomyia complex		R	-	-	-		-	-	-	-		R	-	-	-	-	-	-	-	R	R	-	-	-		-	-	-	-		-	-	R	R
Simulium spp		A	A	A	A		A	A	A	A		R	C	R	A	A	C	C	A	A	-	-	R	C		-	R	R	A		C	C	C	C
Chaoborus sp		C	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Empididae		-	-	-	-		-	-	-	R		-	-	-	-	-	-	-	-	-	R	-	-	-		-	-	-	-		-	-	-	-
Dolichopodidae		-	-	-	R		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Anopheles sp		-	-	-	-		-	R	-	-		-	-	-	C	-	R	-	-	-	-	R	-	-		-	C	-	-		-	-	-	-
Dixella indiana		-	-	-	-		R	-	-	R		-	R	R	R	-	R	-	-	-	-	-	-	-		-	-	-	R		-	R	-	-
DIPTERA: CHIRONOMIDAE																																		
Ablabesmyia spp (2)		R	-	R	-		R	C	R	R		C	C	R	C	C	R	C	C	R	A	A	A	-		-	A	C	C		C	A	C	A
Conchapelopia group		A	R	C	C		A	C	C	R		C	A	C	C	C	R	C	C	A	R	A	C	C		C	A	R	C		A	A	C	A
Clinotanypus sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	R	-	-		-	-	-	-
Labrundinia sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	C	-	-		R	R	-	-
Nilotanypus sp		C	-	R	-		C	R	R	R		R	R	-	-	-	-	-	-	-	-	R	-	-		R	-	-	-		C	A	-	C
Natarsia sp		R	-	-	-		R	R	-	-		-	-	-	-	-	C	C	C	-	C	R	-	-		-	R	-	-		-	-	-	-
Nilothauma sp		-	-	-	-		-	-	-	-		-	-	-	-	-	-	R	-	-	R	C	-	-		-	-	-	-		-	-	-	-
Procladius sp		-	-	-	-		-	-	R	-		-	R	-	-	R	-	-	C	-	-	-	-	-		-	-	-	-		-	-	-	-
Zavrelimyia sp		-	-	-	-		R	-	-	-		-	-	R	-	-	-	-	-	-	R	-	-	-		R	-	-	-		-	-	-	-
Brillia flavifrons		-	-	R	R		-	-	-	-		-	-	-	-	-	R	-	-	R	R	-	-	-		-	-	-	-		-	-	R	-
Corynoneura spp		C	-	R	-		R	R	R	R		-	-	-	-	-	-	-	-	-	-	R	C	-		-	R	-	-		R	C	-	C
Lopescladius sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-		-	-	-	-		-	-	-	-
Thienemaniella spp		R	-	R	-		-	-	-	-		R	R	-	-	-	-	A	R	-	-	-	R	-		-	-	R	C		-	R	R	C
Cricotopus annulator		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	R	R	-	-	-	-		-	-	R	-		-	-	-	-
Cricotopus bicinctus		-	-	-	-		-	-	-	C		-	-	-	R	-	-	R	A	R	-	-	R	R		-	-	-	-		-	R	-	-
Cricotopus cf patens		-	-	-	-		-	-	-	-		-	-	-	-	-	-	R	-	-	-	-	R	-		-	-	-	-		-	-	-	-
Cricotopus cylindracaeus		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	R	-	-	-	-	-		-	-	-	-		-	-	-	-
Cricotopus fugax		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	R	-	-	-	-	-		-	-	-	-		-	-	-	-
Cricotopus infuscatus		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	R		-	-	-	R		-	-	-	C
Cricotopus luciae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-

Date:	06/13					06/14					06/15					07/16				7/17					07/18								
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Cricotopus triannulatus gr			-	-	-	-		-	-	-	R			-	-	-	-	-	R	-	-	-	-	-		-	-	-	-		-	-	-	-
Cricotopus vierrensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Eukiefferiella claripennis gr			-	-	-	-		-	-	-	R			-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Limnphyes sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-
Nanocladius sp			-	-	-	-		-	-	-	-		-	-	-	-	-	-	R	-	-	C	-	-		-	-	R	R		-	R	R	-
Orthocladius carlatus			-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	R	R		-	-	-	R		-	-	-	R
Orthocladius dubitatus		-	-	-	-			-	-	R	R		-	-	-	-	-	R	R	-	-	-	-	-		-	-	-	R		-	-	R	R
Paracricotopus sp			-	-	-	-		-	-	-	-		-	-	R	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-
Parametriocnemus lundbecki		A	C	A	A		R	R	-	-				R	-	R	R	R	R	-	-	C	R	R	R	-		-	-	-	R		R	-	-	-
Rheocricotopus robacki		-	-	-	-				-	C	-	-		-	R	-	-	-	-	R	C	-	-	-	-	-		-	-	-	-		-	-	-	-
Synorthocladius sp		-	-	-	-			-	-	R	R	-	-	-	-			-	-	A	R	-	C	R	-	-	C	-	R	C		-	-	R	C
Tvetenia bavarica gr		C	-	C	-			R	-	-	-	-	-	-	-			R	-	R	-	C	-	-	-	-	-	-	-	-		-	-	-	-
Xylotopus par		-	-	-	-		-	-	-	-		-	-	R	-			R	-	R	R	-	-	R	-	-	-	-	R		-	R	-	-
Potthastia longimana		-	-	-	-			-	-	-	R		-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-					
Chironomus sp		-	-	-	-		-	-	-	-		-	-	-	R		-	-	-	-	-	-	-	R	-	-	-	-	-		-	R	-	-
Cryptochironomus spp		-	R	-	-		C	C	R	-		C	C	R	-			R	C	R	R	R	C	R	-		R	C	R	-		C	C	R	C
Cryptotendipes sp		-	-	-	-		-	R	-	-		-	-	R	-			-	-	-	-	-	C	-	-	-	-	-	-	-		-	R	-	-
Dicrotendipes spp		-	-	-	-		-	-	-	R			-	-	R	-		-	-	C	C	-	-	-	R	-		-	R	C	A		-	R	-	A
Endochironomus sp		-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	R	-		-	-	-	-		-	-	-	-
Microtendipes spp		A	A	A	C		R	A	A	C		R	A	R	C		R	C	C	A		-	A	A	C	-		C	-	A	A		A	A	A	A
Parachironomus carinatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	R
Paramerina sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-		-	-	-	-		-	-	-	-
Paratendipes sp		-	R	R	-		R	-	C	R		-	-	C	R		-	-	C	R		C	-	C	-	-		-	R	-	-		-	-	R	C
Phaenopsectra spp		-	R	-	-		C	-	R	R		-	-	-	R		-	-	-	C		R	R	C	C	-		-	R	C	R		-	-	-	R
Polypedilum flavum		A	A	A	A		A	A	A	C		C	C	-	R		R	C	A	C		A	C	C	A	C		R	C	-	C		R	A	-	C
Polypedilum aviceps		-	-	-	-		-	-	-	-		-	-	R	-		C	C	-	-		C	-	-	-	-		-	R	-	-		C	-	R	-
Polypedilum halterale		-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-		-	-	C	R	R		-	-	-	C		-	-	-	-
Polypedilum illinoense		-	-	-	-		-	-	-	-		-	R	-	-		-	R	C	R		C	-	R	-	C		-	C	-	-		C	C	-	C
Polypedilum fallax		R	-	-	-		-	-	-	-		-	R	-	-		R	-	-	-		-	R	-	C	-		-	-	-	-		-	R	-	-
Polypedilum scalaenum		-	R	R	R		A	C	C	C		-	C	-	C		-	-	R	R		-	-	-	-	-		-	-	-	-		-	-	-	-
Pseudochironomus sp		-	-	-	-		-	-	-	-		-	-	-	R		-	-	-	-		-	-	R	-	-		-	-	-	-		-	-	-	-
Stenochironomus sp		C	C	-	-		-	-	R	-		C	-	-	-		R	-	C	-		-	-	A	R	-		C	C	C	C		R	C	R	C
Stictochironomus sp		-	-	-	-		-	-	C	-		-	-	-	-		C	A	A	C		-	A	C	-	-		A	A	A	C		-	A	C	-
Tribelos sp		C	C	-	R		C	R	A	C		A	C	A	A		-	R	A	A		R	R	A	A	R		-	A	A	C		-	A	A	A
Xenochironomus xenolabis		-	-	-	-		-	-	-	-		-	A	-	-		-	-	-	-		-	-	-	R	-		-	-	-	R		-	-	-	
Cladotanytarsus sp		-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	R	-		-	-	-	-		R	-	-	-
Paratanytarsus sp		R	-	R	R		-	R	-	-		-	-	-	-		-	-	C	R		A	-	-	-	-		-	-	R	-		R	-	-	C
Rheotanytarsus spp		R	-	C	R		-	R		R	C	-	-	-	-		-	C	C	R		R	-	R	R	C		C	R	C	-		R	C	R	C
Tanytarsus spp		R	-	-	-		R	C		C	-	-	R	R	R		C	R	A	-		-	R	C	A	R		-	R	C	A		C	A	C	A
OLIGOCHAETA																																	
Limnodrilus spp (hofmeisteri)			-	-	-	-		R	-		C	-		-	R	C	R		C	C	C	R	-	R	C	C	-		-	R	R	R		C	R	-	-

Date:	06/13					06/14					06/15					07/16				7/17					07/18					07/19				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Ilyodrilus templetoni		R	-	-	-		-	R	-	-		C	-	-	-		-	-	-		-	-	-	-		-	-	-	-		-	-	-	-
Nais spp		-	-	-	-		R	R	R	R		-	-	-	-		-	-	R		R	R	-	-		-	-	-	-		-	-	R	-
Pristinella sp		-	-	-	-		-	-	-	-		-	-	-	-		-	R	-	R	-	-	-	-	-	-	-	-	-		R	-	-	-
Slavinia appendiculata		-	-	-	-		-	-	-	R		-	-	-	-		-	-	-		-	-	-	R	R	-	-	-	-		-	-	-	-
Stylaria lacustris		-	-	-	-		-	-	-	-		-	-	-	R		-	-	-		-	R	-	-	-	-	-	-	-		-	-	-	-
Lumbriculidae																																		
Lumbriculus variegates		R	-	R	C		-	R	C	R		-	R	-	C		A	R	C	C	-	-	C	C	A		-	C	R	A		C	A	C	A
Ecclipidrilus spp		C	-	-	-		R	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
Megadriles		R	R	R	-		-	-	-	-		-	-	-	-		A	R	C	-	C	-	-	-	-	-	-	-	-		-	-	-	-
Cambarinicolidae		-	-	-	-		-	-	-	R		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
CRUSTACEA																																		
Crangonyx spp		-	R	-	-		-	-	R	-		-	-	-	-`		-	-	-	-	C	-	-	-	-	-	-	-	-		R	-	-	-
Hyallela azteca		C	C	R	R		-	C	C	C		-	R	R	R		-	-	R	R	-	-	A	R	-		-	A	C	-		-	-	R	-
Caecidotea sp		-	-	-	R		-	-	R	R		-	-	R	-		-	-	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Cambarus sp		A	R	C	-		A	C	C	C		A	A	C	C		R	A	C	C	-	C	C	C	C	A	A	A	C		C	A	-	C
Procambarus acutus		-	-	-	-		-	-	-	-		-	-	R	-		-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
MOLLUSCA																																		
Elimia sp -		A	R	-	R		A	C	R	R		A	A	C	A		A	A	C	C	C	A	A	C	C	A	A	A	C		A	-	C	R
Campeloma decisum		C	-	R	-		C	-	C	-		-	R	R	-		C	C	-	C	R	R	R	-	-	C	C	-	-		C	C	-	-
Physa sp		A	A	C	C		R	R	R	R		C	R	C	R		R	R	R	R	R	-	R	R	-	-	R	A	C		R	R	-	R
Pseudosuccinea columella		-	-	-	-		-	-	-	-		-	-	-	-		-	R	-	-	-	-	-	-	-	-	-	-	-		-	R	-	-
Helisoma anceps		R	-	-	-		-	-	-	R		-	-	-	C		-	R	-	-	-	-	C	-	-	-	R	R	A		-	C	-	-
Menetus dilatus		-	-	-	-		-	-	-	-		-	-	-	-		R	-	R	C	R	R	C	C	-	C	R	C	R		R	C	-	R
Ferrissia sp		-	-	-	R		-	-	R	-		-	-	-	-		R	-	R	-	-	-	-	R	C	R	R	-	R		C	C	C	C
Sphaerium spp		-	C	-	-		C	A	R	-		R	C	-	-		C	A	C	-	-	-	C	-	-	-	C	-	-		-	-	-	-
Pisidium spp		-	-	-	-		-	-	-	-		-	-	-	-		-	-	C	-	-	-	-	-	-	-	-	-	R		-	R	-	-
Corbicula fluminea		A	-	-	-		A	-	C	-		C	C	R	C		A	A	C	R	-	C	A	-	-	C	A	-	R		A	C	R	-
Elliptio sp -		-	-	-	-		R	A	R	-		C	R	-	-		-	-	-	-	-	-	R	-	-	-	-	-	-		-	-	-	-
OTHER																																		
Dugesia tigrina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	C	-	R	R	R	C	-	-	-	-	-	C	C	R	-
Cura foremanii	R	C	C	A		A	A	R	C		-	R	-	A		C	-	C	-	-	-	-	-	-		R	-	-	-		-	-	-	-
Hydrolimax grisea	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prostoma graecens	-	-	-	-		-	-	-	-		-	-	-	-			-	-	-		-	-	-	-		-	-	R	-		-	-	-	R
Hydracarina	-	-	-	-		-	-	-	-		-	-	-	-		R	A	C	R		R	-	R	-	R		-	A	A	C		R	-	C	C
Desserobdella phalera	-	-	-	-		-	-	-	-		-	-	-	-			-	-	-			-	-	-	-		-	R	-	R		-	-	-	-
Helobdella triserialis	-	-	-	-		-	-	-	-		R	-	-	-		-	-	-	-		-	-	R	-	-		-	R	-		-	-	-	-
Placobdella ornata	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-		-	R	-	-	-		-	-	-	-		-	-	-
Placobdella papillifera	-	R	-	-		-	-	R	-		-	-	-	-		-	-	-	-		-	-	-	-	-		-	-	-	-		-	-	-
Placobdella parasitica	-	-	-	-		R	-	-	R		-	-	-	-		-	-	-	-		-	-	-	-	-		-	-	-			-	-	-
Hemiptera: Lethocerus	-	-	-	-		-	-	-	-		-	-	-	-		-	R	-	-		-	-	-	-	-		-	-	-	-		-	-	-
Hemiptera: Gerridae	-	-	-	-		-	-	-	-		-	-	-	-		-	R	-	-		-	R	R	R	-		-	-	-	-		C	C	-	-
Hemiptera: Corixidae	-	-	-	-		-	-	-	-		-	-	-	R		-	-	-	-		-	-	-	-	-		-	-	-			-	-	-
Hemiptera: Notonecta sp	-	-	-	-		-	R	-	-		R	-	-	-		-	-	-	-		-	-	-	-	-		-	-	-	-		-	-	-

Date:	06/13					06/14					06/15					07/16				7/17					07/18					07/19				
Site:	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4
Hemiptera: Ranatra		-	-	-	-		-	-	-	-		-	-	-	R	-	-	-	-	-	-	-	-	-		R	-	-	-		-	-	-	-

Appendix 3. Intolerant Taxa in Bolin and Morgan Creek.

3A. Changes in key indicator species (Highly intolerant). Times of greatest abundance are highlighted in blue. TV = Tolerance Value; lower numbers indicate most intolerant species (all species selected here are considered intolerant). R=Rare, C=Common, A=Abundant.

		Chimarra (TV = 3.3)				*Eccoptura xanthenes* (TV = 4.7) or *Acroneuria abnormis* (TV = 2.1)				
Date	Sites:	1	2	3	4	1	2	3	4	
09/2000			A	R	-		C	C	C	
12/2000			A	-	-		-	-	A	
03/2001			R	-	-		R	C	-	Follows drought
06/2001			C	R	R		R	R	C	
09/2003		R	A	A	A	C	C	C	C	
09/2004		A	A	A	A	R	R	R	-	
08/2005		A	C	R	C	R	R	C	C	
12/2008		A	A	A	A	R	C	A	C	
07/2009		A	C	A	A	-	-	R	R	
03/2010		C	R	A	A	R	R	C	-	
03/2011		A	C	-	R	C	-	-	-	
06/2012		A	R	–	C	R	-	A	R	
06/2013		A	A	A	A	-	-	-	-	
06/2014		A	A	A	A	-	-	R	R	
06/2015		A	A	A	A	-	-	-	C	
07/2016		A	A	C	A	-	-	R	C	
07/2017		A	R	A	A	-	-	R	R	
07/2018		C	-	C	A	-	-	C	A	
07/2019		A	A	A	A	-	-	-	-	

3B. Selected intolerant species at Bolin Creek sites 1-4 and Morgan Creek (M), 2009-2018.
Note that seasonal changes produce a slightly different set of species for each date.

	07/09					03/10					03/11				
	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M
Isonychia spp	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-[1]
Acentrella ampla (March only)						-	-	-	-	A	-	-	-	-	A
Leucrocuta Aphrodite	-	-	-	-	A	-	-	-	-	C	-	-	-	-	C
Baetis pluto	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-
Acroneuria abnormis	-	-	R	R	C	-	-	C	–	A	R	-	-	-	-
Amphinemura sp (March only)						C	R	-	R	A	C	-	R	R	A
Clioperla clio (March only)						-	-	-	-	R	-	-	-	-	A
Isoperla spp (March only)						-	-	-	-	C	-	-	-	-	A
Neophylax oligius	A	R	-	-	-	-	-	-	-	-	-	-	-	-	R
Chimarra sp	A	C	A	A	A	C	R	A	A	-	A	C	-	R	-
Rhyacophila fenestra (March only)							C	-	R	C	A	C	-	C	-
Psephenus herricki	A	-	A	A	A	A	R	A	C	A	A	R	C	A	C
Elimia sp	A	A	C	A	-	A	C	C	C	-	A	A	-	C	–
Sum*	40	14	24	31	53	29	6	27	20	57	37	14	7	15	40

	06/12					06/13					06/14					06/15				
	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M
Isonychia spp	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	R	-	-	A
Leucrocuta aphrodite	-	-	-	-	A	-	-	-	-	A	-	-	-	-	A	-	-	-	-	A
Baetis pluto	-	-	-	-	-	-	-	-	-	-	C	A	R	R	A	R	R	C	-	A
Acroneuria abnormis	-	-	A	-	C	-	-	-	-	-	-	-	R	R	C	-	-	-	C	A
Neophylax oligius	A	-	-	-	-	C	C	-	-	R	A	A	-	-	A	-	-	-	-	A
Chimarra sp	A	R	-	C	-	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Psephenus herricki	A	-	C	C	C	A	R	C	A	A	A	R	R	A	A	R	C	R	A	A
Elimia sp	A	A	R	-	-	A	R	-	R	-	A	C	R	R	-	A	A	C	A	C
Sum*	40	11	14	6	26	33	15	13	21	31	43	34	14	23	53	22	25	17	31	73

	07/16				07/17					07/18					07/19				
	1	2	3	4	1	2	3	4	M	1	2	3	4	M	1	2	3	4	M
Isonychia spp	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-	-	-
Leucrocuta aphrodite	-	-	-	-	-	-	-	-	A	-	-	-	-	A	-	-	-	-	A
Baetis pluto	R	-	R	R	-	R	R	-	A	-	R	-	-	A	-	R	-	-	-
Acroneuria abnormis	-	-	R	C	-	-	R	R	A	-	-	C	A	A	-	-	-	-	A
Neophylax oligius	-	-	C	-	-	C	-	-	R	-	-	-	-	R	-	R	-	-	R
Chimarra sp	A	A	C	A	A	R	A	A	A	C	C	C	A	R	A	A	A	A	C
Psephenus herricki	-	A	A	A	R	C	R	A	A	R	C	R	-	A	A	A	R	-	-
Elimia sp	A	A	C	C	A	A	C	C	C	A	A	A	C	-	A	-	C	R	-
Sum*	21	33	18	27	21	18	16	24	57	14	17	17	23	42	30	22	14	11	24

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

[1]Isonychia was abundant in March 2011 further downstream on Morgan Creek, near the Botanical Garden in Chapel Hill.

Appendix 4. Carrboro tributary sites. April 2019.

A sample was collected from Morgan Creek in April 2019. It will be discussed with the other mainstem sites below.

Appendix 4. Carrboro Stream Sites, July 2019
Bolin Creek sites are numbered from most upstream (Site 1) to most downstream (Site 4). Samples from Bolin Creek were collected in July 2019 and Morgan Creek was sampled in April 2019.
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Bolin Creek 1. Site 1 was located upstream of the Winmore development, near the power line crossing. This site drains a largely rural and residential landscape; it is intended as a control site for the higher density residential areas further downstream. This portion of the stream may go completely dry during droughts, but it seems to have had adequate flow over the past several years.

Bolin Creek Site 1 July 2019

This part of Bolin Creek averaged about 4-5 meters wide, with a substrate mainly composed of gravel and rubble. Both the substrate composition and the width, however, were highly variable. There were no significant habitat problems in this section of Bolin Creek, although 2015 samples suggest some water quality problems.

Bolin Creek 2. Site 2 is located downstream of the Winmore development at SR 1777 and is five meters wide. There is private residence on one side of the stream that lacks a buffer zone. Consequently, there is significant bank erosion on one side of the stream. A greenway was constructed on the other bank in 2018 which might have had some impact on increased sand in the creek.
Habitat problems included fewer riffles, bank erosion and lack of a buffer on one side with a greenway added to the other side in 2018 plus a decrease in habitat diversity. A beaver had been present in the upstream segment, but had been removed in 2015.

Bolin Creek Site 2, July 2019.

Bolin Creek 3. Site 3 is located near Waterside Drive. This section of Bolin Creek is very scenic, with frequent recreational use.

Bolin Creek Site 3, July 2019.

There are no significant habitat problems in this portion of the stream, but there was a lack of good bank habitat and large sections of the stream were not flowing.

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

Bolin Creek Site 4, July 2019.

This portion of Bolin Creek is similar to the site on Estes Drive, having good rocky substrate and was six meters wide. Attached filamentous algae was very abundant at the Village Drive site in March 2011, but has not been a problem in later years.

Morgan Creek 1. This site was located at NC 54, upstream of Carrboro. Morgan Creek was chosen as a reference site, although this stream had also been affected by droughts. Prior surveys by the NC Division of Water Quality often produced a Good or Excellent bioclassification for this site. At 8 m wide, it is the largest of the sites sampled.

Morgan Creek Site 1, April 2019

This catchment has a largely rural character, with some minor impacts from nonpoint source runoff. Habitat quality, stream width and substrate composition are similar to Bolin Creek, but with less residential land use. Residential land use, however, has been increasing in the Morgan Creek catchment in recent years.