Biological Assessment of Meeting of the Waters Creek

Summary Report:
Benthic Macroinvertebrate Collections
Summer 2001 and Winter 2002

Christy Jo Geraci
(Under the direction of Dr. Seth R. Reice)

University of North Carolina at Chapel Hill

May, 2002

Introduction

Benthic macroinvertebrates are a good tool for measuring the impacts of development on water quality in streams because they exhibit a wide range of tolerances to changes in water chemistry, flow, substrate size, and food availability. Benthic communities respond to both the acute and chronic degradation in water quality and habitat structure that can result from development within a watershed (Lake 2000, Weiss and Reice 2002). While population sizes of some taxa may not change, less resilient organisms can disappear completely from polluted streams. Depending on their individual life cycles, macroinvertebrates are exposed to environmental stresses for weeks to years, so community structure is evidence of not only present, but of past conditions at a particular site (Reice and Wohlenberg 1992). Decreased macroinvertebrate taxa richness and diversity can signal degraded conditions that chemical monitoring may miss. For these reasons the benthic community is used as an indicator of overall water quality and biological integrity by federal and state environmental protection agencies (Lenat 1993, Kerans and Karr 1994, Barbour et al. 2000).

Urbanization can have significant negative effects on water quality for several reasons. When forest is replaced by impervious surfaces, such as roads and parking lots, storm water has less area to infiltrate the soil and be intercepted by vegetation before reaching the stream channel. This disruption of natural recharge processes caused when the impervious area reaches a threshold of 20% has been shown to increase runoff ratios associated with storm flow, and decrease average base flows (Brun and Band 2000). Increased storm water magnitude and flood frequency can directly affect the benthic community because the force of the water acts as a disturbance, dislodging organisms and washing them downstream. Indirect effects of altering the hydrologic regime on benthic communities are physical changes in stream channel shape and substrate size, and increased inputs of toxic chemicals, fine sediments, and nutrients. Fine sediments disrupt the ability of many species to obtain food and oxygen. Non-point source pollution causes decreased biodiversity of the benthic community over time as the number of pollution-intolerant organisms decreases.

Meeting of the Waters Creek drains the University of North Carolina at Chapel Hill (UNC-CH), and appears to have impaired water quality as a result of runoff from the impervious surfaces. This may have implications for water quality downstream as the creek drains into the North Carolina Botanical Garden and Morgan Creek. The purpose of this study was to assess benthic macroinvertebrate community structure at several locations along Meeting of the Waters creek, and compare these sites to two reference sites on Morgan and Bolin Creeks. Several samples were taken over the course of Summer 2001 and Winter 2001 to track seasonal changes in the benthic community.

Site Description

Seven sites were selected with the help of Sharon Myers from the UNC-CH Department of Environment, Health and Safety to assess the influence of stormwater runoff from the UNC-CH Campus on the benthic community in Meeting of the Waters Creek. Site descriptions are as follows:

Control Sites

UNC-13: Upstream control site on Morgan Creek where it crosses Highway 54.

UNC-14: Upstream control site on Bolin Creek where it crosses the railroad tracks at Estes Dr. Ext.

Test Sites on Meeting of the Waters Creek

UNC-4: Tributary downstream of Kenan Labs and South Rd. Coker Woods

UNC-5: Tributary downstream of Wilson Library and South Rd. UNC-4 and UNC-5 meet just upstream from Kenan Stadium before the stream is piped underground. Coker Woods

UNC-2: Downstream of Boshamer Field where the stream exits the underground pipe.

UNC-12: Downstream from the Dean Smith Center tributary. Downstream of where Boshamer Outfall Trib and Skipper Bowles Outfall Trib combine

UNC-7: Downstream from the Highway 15-501 culvert beside Manning Dr.

Figure 1 illustrates the location of the sampling sites on the three streams.

Sampling Site Locations

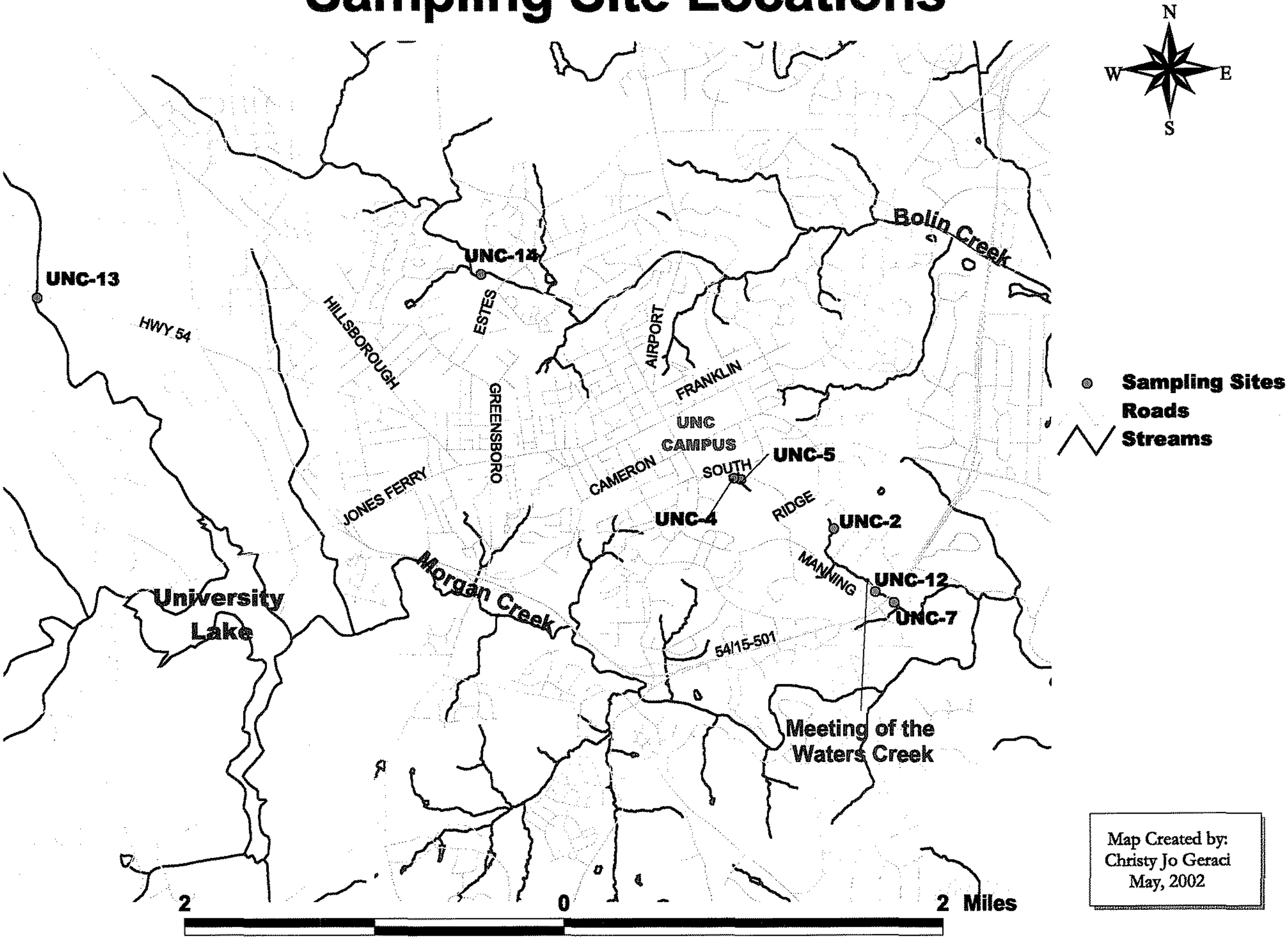

Figure 1.

Methods

Sampling

Benthic macroinvertebrate samples were taken on the following dates:

Summer Dates	Winter Dates
13 June 2001	5 February 2002
18 June 2001	15 March 2002
27 June 2001	
12 July 2001	

UNC sites 4 and 5 were only sampled on 13 June 2001 because of their small size and low richness.

A 250-micron Surber sampler was used to collect replicate subsamples within a riffle zone of the stream. The substrate was disturbed for one minute, and the material collected was preserved in a glass jar using 70% ethanol. Organisms were then sorted from debris in the laboratory using a dissection scope. Invertebrates were counted and identified down to the lowest taxonomic level possible. For aquatic insects this was generally to genus and species level. Prior to sampling each site the following water chemistry field measurements were taken: temperature, pH, dissolved oxygen (DO), conductivity, and salinity (See Appendix B for data summary).

Two subsamples within the same riffle were collected on 13 June 2001. Four subsamples from two riffles were collected on the remaining summer sampling dates. Collecting four subsamples did not yield significantly higher taxa richness or total abundance of organisms. Therefore, two subsamples were taken on the winter sampling dates. This greatly reduced the time need to sort and identify the organisms.

Additional sampling data was included for sites UNC-13 and UNC-14. Kick net samples were taken at each site on 18 September and 9 September, respectively. The samples were sorted in the field, preserved in 70% ethanol, and identified under a dissecting microscope. These samples provide additional data to assess any seasonal changes in community structure at the control sites from early to late summer.

Data Analysis

Data were entered into a Microsoft Excel spreadsheet and analyzed with Systat 9. The following metrics were calculated for each site to assess community structure (Appendix B):

- Taxa richness = number of different invertebrate taxa found per site

- EPT Richness = number of different taxa found from the orders Ephemeroptera, Trichoptera, and Plecoptera.
    - These orders have been shown to be particularly sensitive to degraded water quality.

- Shannon (H') Diversity = $-\sum (p_i \times \ln p_i)$

    p_i = the abundance of each taxa "i" divided by the total abundance
    - This metric measures both taxa richness and evenness of the community

- Total Abundance = total number of individuals per site

- EPT Abundance = number of individuals from the EPT taxa

- Chironomid Abundance = number of Chironomids

These were calculated for each sampling date (Appendix A). Averages were also calculated for each site over the various sampling dates. One-way Analysis of Variance (ANOVA) was used to compare sampling sites, using sampling dates as replicates. Because sites UNC-4 and UNC-5 only have one replicate sample they were not included in the statistical analyses.

Results and Discussion

The data from the summer and winter sampling dates show a less diverse benthic macroinvertebrate community in Meeting of the Waters Creek than in the two upstream control sites on Bolin and Morgan Creek, which is an indicator of degraded water quality and/or habitat conditions. Also, a pattern can be seen in the richness and abundance of macroinvertebrates in Meeting of the Waters Creek from upstream to downstream.

Table 1. Measures of benthic community structure averaged over summer and winter sampling dates (MoW = Meeting of the Waters Creek).

Site	**UNC-14**	**UNC-13**	**UNC-4**	**UNC-5**	**UNC-2**	**UNC-12**	**UNC-7**
Stream	Bolin	Morgan	MoW	MoW	MoW	MoW	MoW
Number of times sampled	7	7	1	1	6	6	6
Total richness	14.00	25.29	7	5	4.50	6.67	8.83
EPT Richness	6.43	13.00	1	1	1.17	2.33	2.33
Total Abundance	316.71	799.86	705	451	75.67	269.83	359.50
EPT Abundance	111.57	304.14	1	1	3.17	23.83	92.00
Chironomid Abundance	135.43	378.86	652	426	55.17	229.17	270.60
H' Diversity	1.49	2.08	0.36	0.27	0.82	0.58	0.99
% Chironomids	46.11	35.14	92.48	94.46	68.31	84.21	65.83

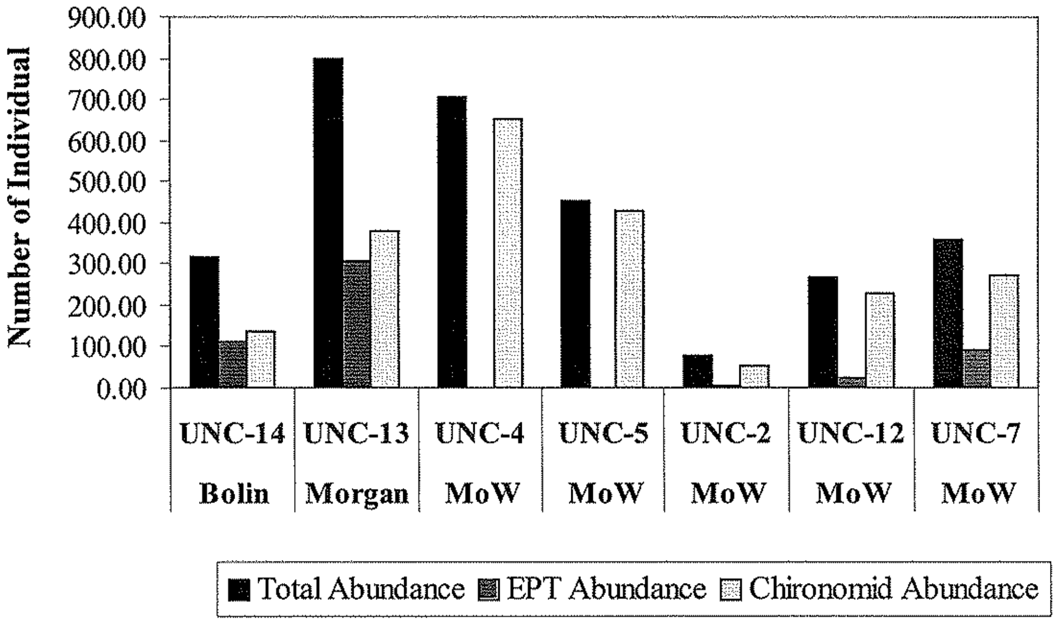

Figure 2. Comparison of total, EPT, and Chironomid abundance for each site averaged over all sampling dates.

Average total abundance was significantly higher at the Morgan control site (UNC-13) than at sites UNC-2 and UNC-12 (p=0.012, Table 1, Figure 2). EPT abundance at UNC-13 was also significantly higher than at UNC-2 and UNC-12 (p=0.022). Abundances are reduced dramatically at UNC-2 as the stream flows out from underground below Boshamer field. The community is made up mainly of tolerant Diptera taxa, with only a few tolerant EPT taxa found. Abundances gradually increase as the stream moves through campus towards the Botanical Garden at UNC-7. UNC-4 and UNC-5 had high total abundances, but again the community at these sites was made up almost entirely of Chironomids and other tolerant Diptera, with only one EPT individual found.

Very low EPT abundances were found in Meeting of the Waters Creek upstream of the Botanical Garden. Chironomid abundance exhibits a different pattern than total and EPT abundance, being highest downstream of Kenan Labs and Wilson Library, and lowest downstream from Boshamer Field individuals. Also, chironomids make up less than 50 percent of the total abundance at the upstream control sites, but greater than 60 percent of the total abundance in Meeting of the Waters Creek. There was no statistical difference, however, in chironomid abundance between the control sites and UNC-2, UNC-12, or UNC-7.

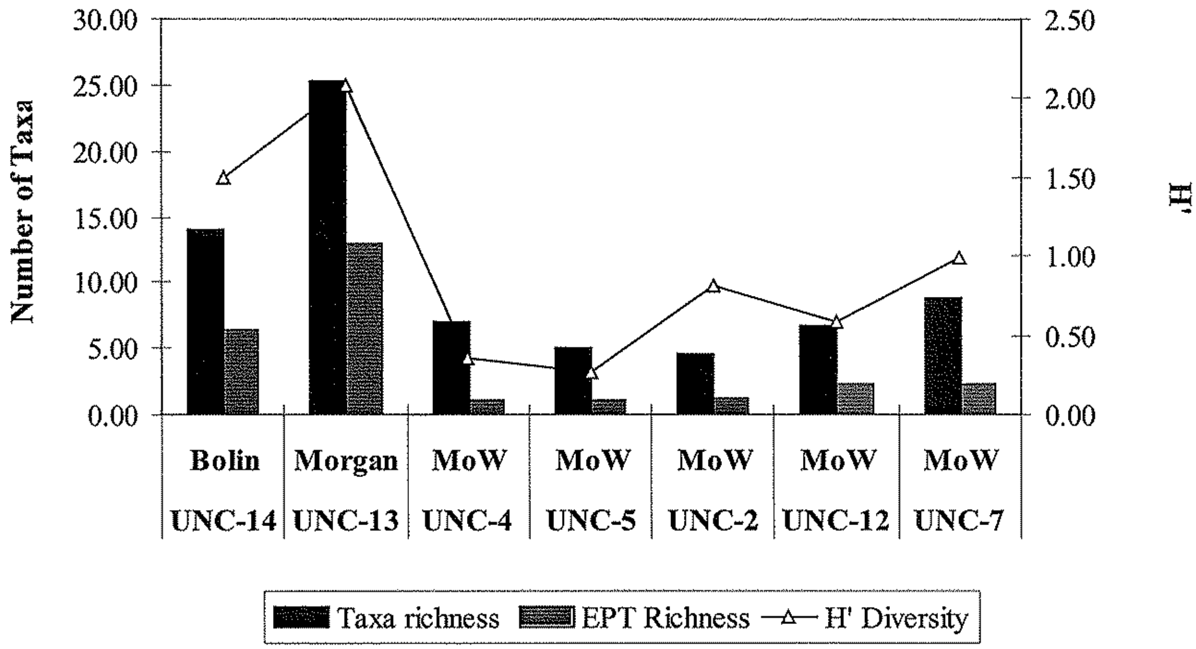

Figure 3. Comparison of taxa richness, EPT richness, and Shannon (H') Diversity at each site averaged over summer and winter sampling dates.

Highly significant differences in total taxa richness (p=0.000) and EPT richness (p=0.000) were found between the control sites and Meeting of the Waters sites, with the highest values found at UNC-13 (Figure 3). The lowest taxa and EPT richness was found at site UNC-2 downstream of Boshamer Field, where the only pollution-tolerant taxa were found (see Appendix A for taxa lists). Richness gradually increases downstream from UNC-2 to UNC-7, but never reaches levels found at the control sites. EPT Richness is suppressed at all sites in Meeting of the Waters Creek, and only the most pollution-tolerant EPT species (*Baetis flavistriga*, *Hydropsyche betteni*, *Cheumatopsyche sp.*) were found overall.

Shannon-Wiener diversity (H') is a reflection of species richness, abundance, and evenness. Figure 3 illustrates the significantly lower diversity in Meeting of the Waters

Creek compared to Morgan and Bolin Creek (p=0.023). Diversity increases as the stream flows away from Boshamer Field, but does not fully recover to levels at the control sites upstream of the UNC-CH campus.

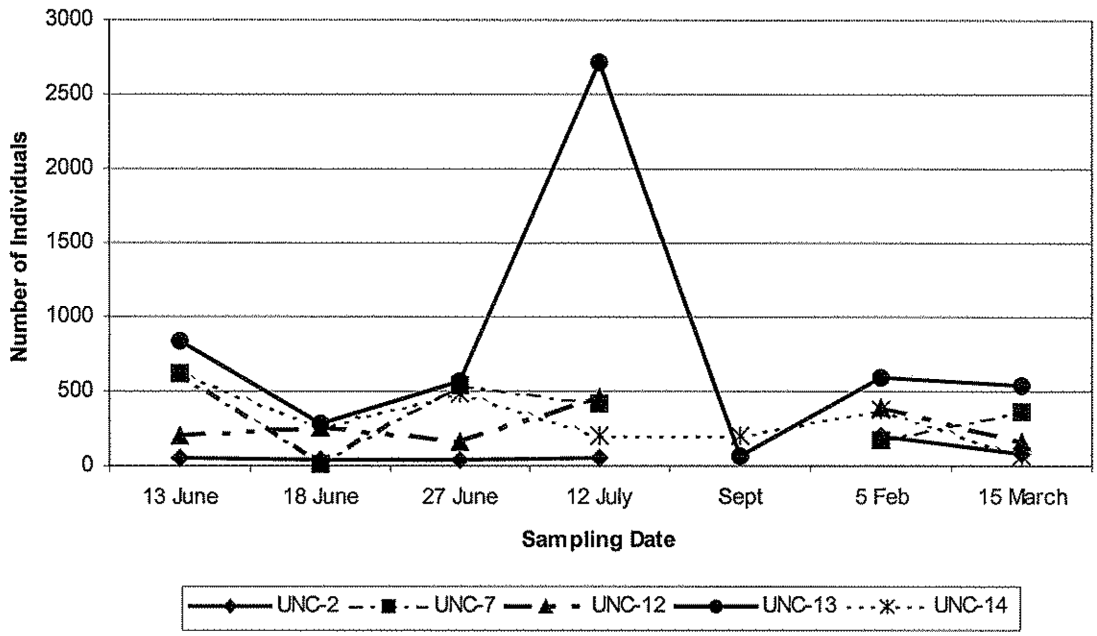

Figure 4. Seasonal fluctuations in total abundance at each sampling site.

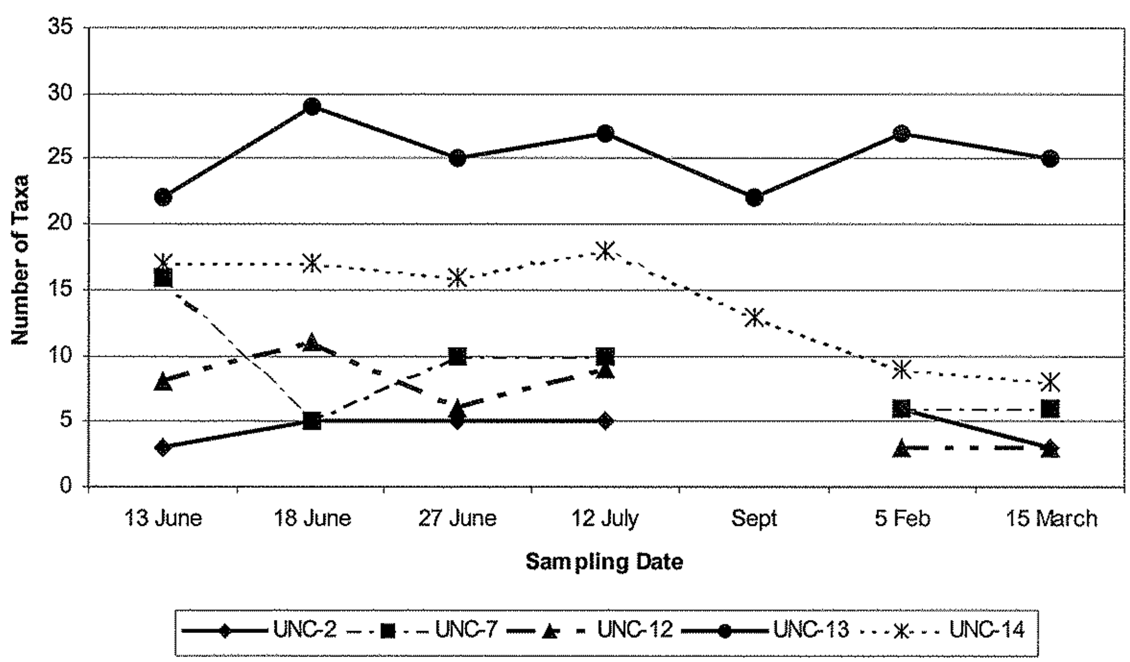

Figure 5. Seasonal fluctuations in taxa richness at each sampling site.

Small seasonal fluctuations in the abundance and taxa richness of organisms is evident in Figures 4 and 5. Abundances can fluctuate naturally over time with the emergence of different aquatic insect populations. Also, the density of organisms can vary greatly within individual riffle zones because they have high spatially heterogeneity. Continued sampling would be necessary to understand further the natural fluctuations in abundances in these streams. A more apparent pattern exists for taxa richness. Figure 5 illustrates that although there is some seasonal fluctuation at each site, and there is overlap among the sites on Meeting of the Waters Creek, there were always more taxa found at the control sites. UNC-13 on Morgan Creek consistently had a much highest number of taxa, including EPT taxa, such as *Acroneuria abnormis, Leuctra sp., Paraleptophlebia sp.,* and *Lype sp.*, which are very intolerant of degraded water quality.

Conclusions and Recommendations

The results of the Summer 2001 and Winter 2002 sampling data suggest that the benthic macroinvertebrate community in Meeting of the Waters Creek is being negatively impacted by non-point source pollution and storm water runoff from the UNC Campus. Significantly lower abundance, richness, and diversity of macroinvertebrates was found in Meeting of the Waters Creek than at the control sites on Morgan Creek and Bolin Creek. EPT taxa richness was very low, and only a few of the more pollution-tolerant EPT taxa, *Baetis flavistriga*, *Cheumatopsyche sp.*, and *Hydropsyche betteni*, were common. These patterns were observed in both the summer and winter seasons, which is evidence of chronically degraded water quality and biological integrity in Meeting of the Waters Creek.

This is likely due to the high percentage of impervious areas in the stream's drainage basin that is negatively affecting the physical and biological processes driving community structure in benthic communities. Construction activities that cause increases in fine sediment inputs to the stream also appear to be having a negative impact. Many of the sites had turbid water and the riffle zones were buried with sand and silt.

Current and future development on the UNC-CH campus should be planned to include effective stormwater mitigation and sedimentation control measures in order to prevent future declines in biological integrity, and allow the stream community to recover. Efforts to repair sewer pipes and prevent them from leaking into the stream will likely result in increased biodiversity downstream of Boshamer Field. Improving the degraded water quality and habitat conditions will likely not only result in the recovery of the benthic community in Meeting of the Waters Creek on the UNC-CH campus, but will also have a positive effect on reaches further downstream into the NC Botanical garden. Continued seasonal biomonitoring of benthic macroinvertebrates is recommended to track changes in community structure over time, which will help the UNC-CH Department of Environment, Health, and Safety understand how campus activities are affecting the biological integrity of Meeting of the Waters Creek.

Appendix A **Macroinvertebrate Data**

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	UNC-2	UNC-2	UNC-2	UNC-2	UNC-2	UNC-2	UNC-4
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002	6/13/2001
Technique	Surber	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	4	4	4	2	2	2
Collembola		5	1				2
Ephemeroptera							
Baetis flavistriga			1				
Baetis intercalaris							
Baetis pluto							
Baetis propinquus							
Caenis sp.							
Isonychia sp.							
Leucrocuta sp.							
Paraleptophlebia sp.							
Pseudocloeon sp.							
Stenonema sp. (early instars)							
Stenonema modestum							
Stenonema vicarium							
Stenacron sp.							
Stenacron carolina							
Stenacron interpunctatum							
Serratella deficiens							
Plecoptera							
Acroneuria abnormis							
Acroneuria lycorias							
Capniidae							
Eccoptura sp.							
Isoperla sp.							
Nemouridae							
Leuctra sp.							
Perlesta sp.							
Perlidae							
Taeniopterygidae							
Trichoptera							
Hydropsychidae (early instar)		4					1
Ceraclea sp.							
Cheumatopsyche sp.			1	2	1		
Chimarra sp.							
Hydropsyche betteni		1	9				
Hydroptila							
Leptoceridae							
Lype sp.							
Neophylax sp.							
Polycentropus sp.							
Psilotreta sp.							

Appendix A **Macroinvertebrate Data**

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	UNC-2	UNC-2	UNC-2	UNC-2	UNC-2	UNC-2	UNC-4
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002	6/13/2001
Technique	Surber	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	4	4	4	2	2	2
Odonata							
Zygoptera early instar							
Aeschna sp.							
Argia sp.							
Boyeria sp.							
Progomphus sp.							
Stylogomphus albistylus							
Megaloptera							
Corydalus cornudas							
Nigronia serricornis							
Diptera							
Anopheles sp.							
Antocha sp.							
Chironomidae	29	23	26	22	155	76	652
Ceratopogonidae							
Empididae				1	10	1	21
Muscidae							
Simulium sp.							1
Tipula sp.	1				1		4
Coleoptera							
Dyticidae							
Ancyronyx sp.							
Dubiraphia vittata							
Dubiraphia quadrinotata							
Ectopria sp.							
Helichus sp.							
Macronychus							
Oulimnus latiusculus							
Optioservis immunis							
Psephenus herricki							
Stenelmis sp.							
Lepidoptera							
Pyralidae							
Mollusca							
Campeloma sp.							
Corbicula fluminea							
Ferrissia sp.							
Physella sp.		2		14	6	1	
Planorbella sp.							
Spheridae							
Hydracarina							
Oligochaeta	18			15	28		24
Tubellaria							

Appendix A

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	**UNC-5**	**UNC-7**	**UNC-7**	**UNC-7**	**UNC-7**	**UNC-7**	**UNC-7**
Sampling Date	6/13/2001	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	2	4	4	4	2	2
Collembola							2
Ephemeroptera							
Baetis flavistriga		64	10	47	110		
Baetis intercalaris							
Baetis pluto							
Baetis propinquus							
Caenis sp.							
Isonychia sp.							
Leucrocuta sp.							
Paraleptophlebia sp.							
Pseudocloeon sp.							
Stenonema sp. (early instars)							
Stenonema modestum							
Stenonema vicarium							
Stenacron sp.							
Stenacron carolina							
Stenacron interpunctatum							
Serratella deficiens							
Plecoptera							
Acroneuria abnormis							
Acroneuria lycorias							
Capniidae							
Eccoptura sp.							
Isoperla sp.							
Nemouridae							
Leuctra sp.							
Perlesta sp.							
Perlidae							
Taeniopterygidae							
Trichoptera							
Hydropsychidae (early instar)							
Ceraclea sp.							
Cheumatopsyche sp.	1	36	3	16	36	2	
Chimarra sp.							
Hydropsyche betteni		37	5	43	142		1
Hydroptila							
Leptoceridae							
Lype sp.							
Neophylax sp.							
Polycentropus sp.							
Psilotreta sp.							

Appendix A

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	UNC-5	UNC-7	UNC-7	UNC-7	UNC-7	UNC-7	UNC-7
Sampling Date	6/13/2001	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	2	4	4	4	2	2
Odonata							
Zygoptera early instar							
Aeschna sp.							
Argia sp.							
Boyeria sp.							
Progomphus sp.							
Stylogomphus albistylus							
Megaloptera							
Corydalus cornudas							
Nigronia serricornis		1		1			
Diptera		1					
Anopheles sp.							
Antocha sp.		4			2		
Chironomidae	426	420	missing	392	32	156	353
Ceratopogonidae							
Empididae		3		3	5	1	
Muscidae							
Simulium sp.		38		31	80		5
Tipula sp.	16	1	1		1		
Coleoptera							
Dyticidae							
Ancyronyx sp.		1					
Dubiraphia vittata							
Dubiraphia quadrinotata							
Ectopria sp.							
Helichus sp.							
Macronychus							
Oulimnus latiusculus							
Optioservis immunis							
Psephenus herricki							
Stenelmis sp.		1					
Lepidoptera							
Pyralidae		7					
Mollusca							
Campeloma sp.							
Corbicula fluminea		7					
Ferrissia sp.				6			
Physella sp.		1				1	1
Planorbella sp.							
Spheridae							
Hydracarina	2			1	2	1	5
Oligochaeta	6	3	1	5	9	20	1*
Tubellaria							

Appendix A

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	**UNC-12**	**UNC-12**	**UNC-12**	**UNC-12**	**UNC-12**	**UNC-12**
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	4	4	4	2	2
Collembola		1				
Ephemeroptera						
Baetis flavistriga				2		
Baetis intercalaris						
Baetis pluto						
Baetis propinquus						
Caenis sp.						
Isonychia sp.						
Leucrocuta sp.						
Paraleptophlebia sp.						
Pseudocloeon sp.						
Stenonema sp. (early instars)						
Stenonema modestum						
Stenonema vicarium						
Stenacron sp.						
Stenacron carolina						
Stenacron interpunctatum						
Serratella deficiens						
Plecoptera						
Acroneuria abnormis						
Acroneuria lycorias						
Capniidae						
Eccoptura sp.						
Isoperla sp.						
Nemouridae						
Leuctra sp.						
Perlesta sp.						
Perlidae						
Taeniopterygidae						
Trichoptera						
Hydropsychidae (early instar)	6	68				
Ceraclea sp.						
Cheumatopsyche sp.		3	3	23	7	
Chimarra sp.						
Hydropsyche betteni	4	3	2	16	4	1
Hydroptila						
Leptoceridae						
Lype sp.						
Neophylax sp.		1				
Polycentropus sp.						
Psilotreta sp.						

Appendix A

Stream	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.	M. of W.
Sampling Site	UNC-12	UNC-12	UNC-12	UNC-12	UNC-12	UNC-12
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Surber	Surber
# replicate samples	2	4	4	4	2	2
Odonata						
Zygoptera early instar						
Aeschna sp.						
Argia sp.						
Boyeria sp.						
Progomphus sp.						
Stylogomphus albistylus						
Megaloptera						
Corydalus cornudas						
Nigronia serricornis						
Diptera						
Anopheles sp.						
Antocha sp.				1		
Chironomidae	148	156	136	392	383	160
Ceratopogonidae						
Empididae	17	5		2		
Muscidae						
Simulium sp.	10	15		15		
Tipula sp.	2	1		1		
Coleoptera						
Dyticidae						
Ancyronyx sp.						
Dubiraphia vittata						
Dubiraphia quadrinotata						
Ectopria sp.						
Helichus sp.						
Macronychus						
Oulimnus latiusculus						
Optioservis immunis			1			
Psephenus herricki						
Stenelmis sp.		1				
Lepidoptera						
Pyralidae						
Mollusca						
Campeloma sp.						
Corbicula fluminea						
Ferrissia sp.			2			
Physella sp.	7			1		1
Planorbella sp.						
Spheridae						
Hydracarina		1				
Oligochaeta	5		12		1*	
Tubellaria						

Appendix A

Stream	Morgan	Morgan	Morgan	Morgan	Morgan	Morgan	Morgan
Sampling Site	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	9/18/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Kick	Surber	Surber
# replicate samples	2	4	4	4	2	2	2
Collembola						1	
Ephemeroptera							
Baetis flavistriga	56	55	60	141			
Baetis intercalaris		1	10	3			
Baetis pluto							
Baetis propinquus							
Caenis sp.			1		2		
Isonychia sp.	10	12		60	2	7	4
Leucrocuta sp.				2	1	4	
Paraleptophlebia sp.	1				1	1	3
Pseudocloeon sp.							11
Stenonema sp. (early instars)	94		84				
Stenonema modestum		30	36	254	6	15	24
Stenonema vicarium		4	12	26	11		2
Stenacron sp.						1	
Stenacron carolina				2			
Stenacron interpunctatum				7	10		3
Serratella deficiens			4	10	1	26	15
Plecoptera							
Acroneuria abnormis	5	3	6	20	2	1	
Acroneuria lycorias						1	
Capniidae						10	
Eccoptura sp.	2						
Isoperla sp.						1	2
Nemouridae							1
Leuctra sp.	5	1	3	9			
Perlesta sp.	1				1		
Perlidae		3				10	4
Taeniopterygidae						2	
Trichoptera							
Hydropsychidae (early instar)							
Ceraclea sp.							1
Cheumatopsyche sp.	84	36	48	291	4	8	13
Chimarra sp.	35	16	4	92	4	77	43
Hydropsyche betteni	53	3	30	64	1	1	
Hydroptila							
Leptoceridae							
Lype sp.							2
Neophylax sp.							
Polycentropus sp.							
Psilotreta sp.		1					

Appendix A

Stream	Morgan	Morgan	Morgan	Morgan	Morgan	Morgan	Morgan
Sampling Site	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**	**UNC-13**
Sampling Date	6/13/2001	6/18/2001	6/27/2001	7/12/2001	9/18/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Surber	Kick	Surber	Surber
# replicate samples	2	4	4	4	2	2	2
Odonata							
Zygoptera early instar							
Aeschna sp.							
Argia sp.					1		
Boyeria sp.							
Progomphus sp.							
Stylogomphus albistylus			8	4	1		
Megaloptera							
Corydalus cornudas		2	1				
Nigronia serricornis	15	12	25	24	3	2	
Diptera		1					
Anopheles sp.							
Antocha sp.				1		1	1
Chironomidae	403	9	103	1470	3	338	326
Ceratopogonidae		1			1		
Empididae	6	6	1				1
Muscidae							
Simulium sp.	5		1	1		43	18
Tipula sp.	1					1	2
Coleoptera							
Dyticidae							
Ancyronyx sp.		1					
Dubiraphia vittata							
Dubiraphia quadrinotata							
Ectopria sp.							
Helichus sp.							3
Macronychus							
Oulimnus latiusculus	4	1	2	8			
Optioservis immunis		17	23	42	1	12	2
Psephenus herricki	5	6	8	5	2		4
Stenelmis sp.	40	55	62	115	3	10	51
Lepidoptera							
Pyralidae		1					
Mollusca							
Campeloma sp.				12		1	
Corbicula fluminea		6		5		2	4
Ferrissia sp.							
Physella sp.	2	1					1
Planorbella sp.						1	
Spheridae			11			13	
Hydracarina	11	1	10	44	1		
Oligochaeta	1	4	9	3			
Tubellaria		1					

Appendix A

Stream	Bolin	Bolin	Bolin	Bolin	Bolin	Bolin
Sampling Site	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**
Sampling Date	6/18/2001	6/27/2001	7/12/2001	9/8/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Kick	Surber	Surber
# replicate samples	4	4	4	2	2	2
Collembola			1			
Ephemeroptera						
Baetis flavistriga	41	36	26	4		
Baetis intercalaris				1		
Baetis pluto						
Baetis propinquus						
Caenis sp.						
Isonychia sp.			5			
Leucrocuta sp.						
Paraleptophlebia sp.						
Pseudocloeon sp.						
Stenonema sp. (early instars)		1				
Stenonema modestum	1		5	2	1	1
Stenonema vicarium						
Stenacron sp.		1	1			
Stenacron carolina						
Stenacron interpunctatum						
Serratella deficiens						
Plecoptera						
Acroneuria abnormis	1			2		
Acroneuria lycorias						
Capniidae						
Eccoptura sp.						
Isoperla sp.						
Nemouridae						
Leuctra sp.		1	1			
Perlesta sp.						
Perlidae						
Taeniopterygidae						
Trichoptera						
Hydropsychidae (early instar)	33					
Ceraclea sp.						
Cheumatopsyche sp.	13	36	26	9	22	4
Chimarra sp.	2		2		2	
Hydropsyche betteni	14	7	20	72	7	2
Hydroptila						
Leptoceridae		1				
Lype sp.						1
Neophylax sp.						
Polycentropus sp.						
Psilotreta sp.	2					

Appendix A

Stream	Bolin	Bolin	Bolin	Bolin	Bolin	Bolin
Sampling Site	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**	**UNC-14**
Sampling Date	6/18/2001	6/27/2001	7/12/2001	9/8/2001	2/5/2002	3/15/2002
Technique	Surber	Surber	Surber	Kick	Surber	Surber
# replicate samples	4	4	4	2	2	2
Odonata						
Zygoptera early instar						
Aeschna sp.						
Argia sp.				1		
Boyeria sp.						
Progomphus sp.						
Stylogomphus albistylus						
Megaloptera						
Corydalus cornudas						
Nigronia serricornis						
Diptera						
Anopheles sp.						
Antocha sp.			6			
Chironomidae	66	323	69	49	289	53
Ceratopogonidae	1					
Empididae	1					
Muscidae						
Simulium sp.	62	6	14		50	3
Tipula sp.		1				1
Coleoptera						
Dyticidae						
Ancyronyx sp.						
Dubiraphia vittata				2		
Dubiraphia quadrinotata				1		
Ectopria sp.						
Helichus sp.						
Macronychus						
Oulimnus latiusculus		1	1			
Optioservis immunis	2				4	
Psephenus herricki	1	1	1	21		
Stenelmis sp.	5	12	15	41		1
Lepidoptera						
Pyralidae						
Mollusca						
Campeloma sp.						
Corbicula fluminea					1	
Ferrissia sp.						
Physella sp.						
Planorbella sp.					1	
Spheridae		9				
Hydracarina	2	41	9			
Oligochaeta		6	5	1		
Tubellaria	4		2			

Appendix B **Field Water Chemistry Measurements**

Site	Date	pH	Dissolved Oxygen	Temperature	Conductivity
UNC-2	13-Jun-01	6.3	5.3	21.00	0.22
UNC-2	18-Jun-01	6.7	6.1	23.00	1.20
UNC-2	27-Jun-01	6.4	7.2	23.00	0.25
UNC-2	12-Jul-01	6.3	6.6	22.00	0.41
UNC-2	5-Feb-01	7.1	8.6	12.00	0.22
UNC-2	15-Mar-01	6.9	broken	18.00	0.21
	Average	**6.6**	**6.8**	**19.8**	**0.4**
UNC-4	13-Jun-01	6.1	4.2	28.00	0.15
UNC-5	13-Jun-01	6.0	8.2	19.00	0.15
UNC-7	13-Jun-01	7.1	8.1	22.00	0.26
UNC-7	18-Jun-01	7.0	8.3	22.00	0.30
UNC-7	27-Jun-01	6.8	9.2	24.00	0.27
UNC-7	12-Jul-01	7.0	9.0	25.00	0.42
UNC-7	5-Feb-01	7.1	13.4	5.00	0.26
UNC-7	15-Mar-01	7.5	broken	18.00	0.25
	Average	**7.1**	**9.6**	**19.3**	**0.3**
UNC-12	13-Jun-01	6.8	6.1	22.00	0.30
UNC-12	18-Jun-01	6.5	7.4	21.00	0.34
UNC-12	27-Jun-01	6.6	6.7	24.00	0.03
UNC-12	12-Jul-01	6.7	8.4	22.00	0.40
UNC-12	5-Feb-01	6.9	11.6	6.00	0.27
UNC-12	15-Mar-01	7.0	broken	19.00	0.23
	Average	**6.8**	**8.0**	**19.0**	**0.3**
UNC-13	13-Jun-01	6.5	6.7	22.00	0.12
UNC-13	18-Jun-01	6.5	7.7	21.00	0.11
UNC-13	27-Jun-01	6.3	8.8	21.00	0.10
UNC-13	12-Jul-01	6.5	8.4	22.00	0.12
UNC-13	5-Feb-01	6.8	13.7	4.00	0.12
UNC-13	15-Mar-01	7.3	broken	13.00	0.11
	Average	**6.7**	**9.1**	**17.2**	**0.1**
UNC-14	13-Jun-01	6.7	6.9	23.00	0.12
UNC-14	18-Jun-01	6.5	7.9	23.00	0.11
UNC-14	27-Jun-01	6.5	8.9	23.00	0.10
UNC-14	12-Jul-01	6.7	8.3	24.00	0.12
UNC-14	5-Feb-01	6.9	13.2	5.00	0.13
UNC-14	15-Mar-01	7.6	broken	15.00	0.13
	Average	**6.8**	**9.0**	**18.8**	**0.1**

References:

Barbour M.T., W.F. Swietlik, S.K. Jackson, D.L. Courtemanch, S.P. Davies, C.O.Yoder. 2000. Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity. Hydrobiologia 422: 453-464.

Brun, S.E., and L.E. Band. 2000. Simulating runoff behavior in an urbanizing watershed. Computers, Environment and Urban Systems 24: 5-22.
Lake, P.S. 2000. Disturbance, patchiness, and diversity in streams J N Am Benthol Soc 19 (4): 573-592.

Kerans, B.L., and J.R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4(4): 768-785.

Lake, P.S. 2000. Disturbance, patchiness, and diversity in streams J N Am Benthol Soc 19 (4): 573-592.

Lenat, D.R. 1993. A biotic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality ratings. J. N. Am. Benthol. Soc. 12(3): 279-290.

Reice, S.R. and M. Wohlenberg. 1992. Monitoring freshwater benthic macroinvertebrates and benthic processes: Measures for assessment of ecosystem health. Pages 287-305 In: Freshwater biomonitoring and benthic macroinvertebrates. V. Resh and D. Rosenberg, eds. Chapman and Hall, New York.

Weiss, J.W. and S.R. Reice. 2002. A multivariate analysis of factorial BACI designs: disentangling the effects of treatment and phenology. In preparation.