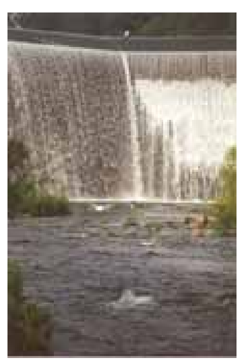
2002 BENTHIC BIOLOGICAL ASSESSMENT OF THE LOWER MILL RIVER

HAMDEN / NEW HAVEN (CT)

prepared for :

South Central Connecticut
Regional Water Authority
90 Sargent Drive
New Haven CT 06511



prepared by :

ENSR INTERNATIONAL
Marine and Coastal Center
89 Water Street
Woods Hole, MA 02543

January 2003

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

The purpose of this study is to provide baseline information for future management decisions in conjunction with possible alterations to present stream flows. The study provides quantitative and qualitative information about general habitat characteristics and benthic macroinvertebrate community structure at five locations along the lower Mill River in Hamden and New Haven, CT. This study supplements and updates three similar surveys carried out in 1998, 2000, and 2001 (ENSR 1998, 2000, 2001). Surveys in 2000, 2001 and 2002 included a lower number of variables than the 1998 study, but habitat and macroinvertebrate characterization was carried out with more detail than in 1998, all as a function of project input from interested parties. It is intended that a review of all data will be conducted before the new Whitney water treatment facility comes on line to evaluate any potential impact thresholds.

METHODS

General methods in 2002 followed those applied in the 2000 and 2001 surveys (ENSR 2000, 2001). Samples were collected in June and August 2002, at the peak of the tidal outflow (low tide). Sampling locations were the same as in previous studies (Figure 1). Sampling stations were longitudinal stretches, ranging from 85 to 300 ft in length (~25-90 m). Each sampling station was characterized for general habitat and instream water quality at representative sites. A single sample per site was used to determine water quality parameters. Macroinvertebrates were collected as duplicate D-frame dip-net samples at each station.

Aquatic habitat was evaluated in a qualitative to semi-quantitative way adopting the same framework used in the previous studies (ENSR 1998, 2000, 2001). This was a modified version of the USEPA Rapid Bioassessment Protocol (Physical Characterization / Water Quality Assessment) (Barbour et al. 1999). Aquatic habitat characterization included features such as surrounding land use, canopy cover, flow, and substrate composition for each sampling station. Water quality was assessed in a quantitative way with *in situ* determinations of water temperature, dissolved oxygen content, conductivity, turbidity, and pH at each sampling station.

Timed (two minutes) D-frame dip-net sampling was used to collect macroinvertebrates. This method is commonly used as a multi-habitat rapid bioassessment technique (Barbour et al. 1999). Where present, riffle habitats were sampled. Otherwise, run habitats were selected. Macroinvertebrates were captured in the net by dislodging the substrate up to 1 ft (0.3 m) upstream of the dip-net. Two subsamples per sampling station were collected. Each subsample consisted of a two-minute collection. Subsamples were preserved in 70%

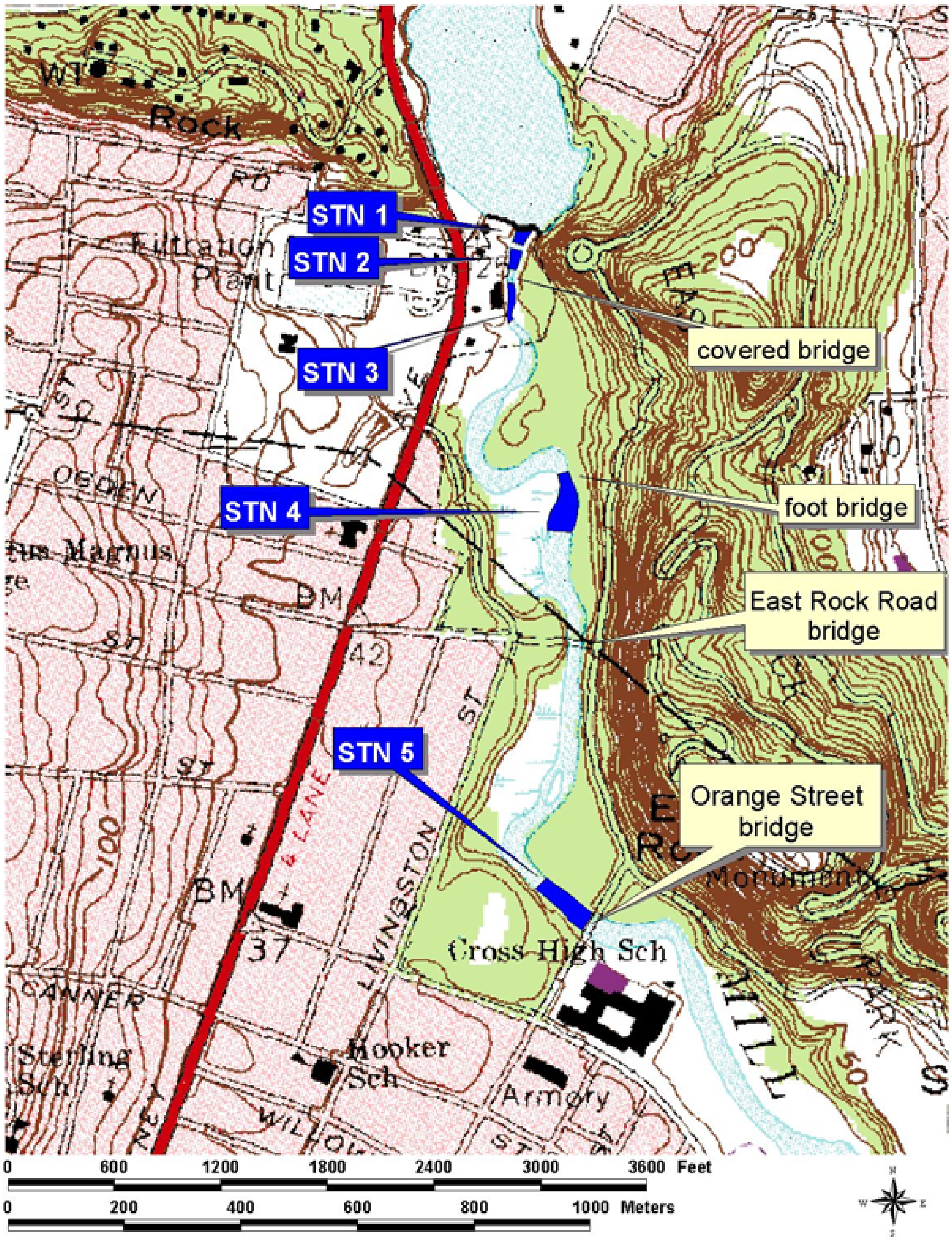


Figure 1. Locations of the five sampling stations along the Lower Mill River in Hamden (stations 1-4) and New Haven (station 5) (from ENSR 2000).

ethanol for laboratory analysis. Macroinvertebrates were sorted, identified to the lowest practical taxonomic level, and counted. Samples were collected during the period of low tide on both sampling dates (low tide listed as 13:30 on 17 June and 16:00 on 19 August).

The two macroinvertebrate subsamples were analyzed separately, but combined into a single sample per station for data analysis. Variability among subsamples was slight and similar to that found in previous surveys. Numerical analysis included relative abundance and dominance patterns, species richness, diversity, and evenness. Species richness was expressed as number of taxa (*S*). Species diversity indices quantify the degree of dominance (or lack thereof) of taxa within a community. When one or a few taxa dominate a community, diversity is low. Species diversity was calculated as the Shannon-Wiener index (*H'*), which includes both distribution/dominance patterns and number of taxa (e.g., a community with a high number of taxa is more "diverse" than a community with a low number of taxa, all other things being equal). Evenness (Pielou's index *J'*) normalizes *H'* in relation to number of taxa, and therefore provides the basis for a quantitative diversity comparison between communities with different *S* values (the scale is always 0 to 1). Mathematical descriptions of the indices can be found in Zar (1984).

RESULTS

Habitat Characterization

Predominant land use (forest and residential) and sources of watershed pollution (storm pipes discharging at several locations between stations 2 and 5) were the same as in the previous surveys (Table 1). Sources of pollution to the lower Mill River also include combined sewer overflows (CSOs), one of which is located in the study area (East Rock Road). CSOs can have strong but intermittent water quality impacts below station 2. Canopy cover was maximum at station 3 and minimum at station 1. Major shore or bank erosion was not observed, as in the previous surveys.

Flow (as estimated or calculated at the spillway) was 85 MGD at the time of June sampling and 21 MGD at the time of August sampling in 2002. June 2002 sampling followed a typical late spring rainstorm and the August 2002 samples were taken during a summer dry spell. The spring flows were similar to values recorded in the 1998, 2000, and 2001 surveys. The August 2002 flow was lower than other observations taken during this month in previous years. August 2000 and 2001 sampling followed significant rain events and thus flows were higher than might be expected during late summer. Sampling was not conducted during the very dry spring and summer of 1999. August 2002 flow was the lowest observed at any time during sampling thus far. Based on factors such as tidal influence and watershed hydrologic characteristics, a wide range of flow conditions and associated variations in the aquatic benthic community are anticipated. Tidal influences are apparent at stations 4 and 5, while variation in flow from Lake Whitney is the more dominant current influence at stations 1-3.

Table 1. Lower Mill River habitat characterization – June and August 2002. Flow, as estimated at the Lake Whitney outlet, was 128 cfs on 17 June and 33 cfs on 19 August. Watershed characteristics did not change from June to August.

	stn 1		**stn 2**		**stn 3**		**stn 4**		**stn 5**	
parameters	17 Jun	19 Aug	17 Jun	19 Aug	17 Jun	19 Aug	17 Jun	19 Aug	17 Jun	19 Aug
length of sampling segment	85 ft (26 m)		150 ft (46 m)		300 ft (91 m)		300 ft (91 m)		300 ft (91 m)	
♦ watershed / bank features										
predominant surrounding land use	forest/ residential		forest/ residential		forest/ residential		forest/ residential		forest/ residential	
canopy cover	open		some shade (<40%)		mod. shade (40-80%)		some shade (<40%)		some shade (<40%)	
dominant riparian vegetation	shrubs		shrubs		trees		trees/shrubs		trees	
bank stability[1]	stable		stable		stable		stable		stable	
other notable features	near dam		near dam		downstream of dam		downstream of dam		downstream of dam	
♦ in-stream features		Low flow								
general habitat type (%) :										
riffle	100	100	100	100	50	40	-	-	-	-
run	-	-	-		50	60	50	20	95	20
pool	-	-	-		-	-	50	80	5	80
estimated stream width (ft) :	50	10	50	20	100	80	100	80	100	80
estimated stream depth (ft) :										
riffle	0.8	1.0	1.0	0.2	0.5	0.5	-	-	-	-
run	-	-	-	-	1.0	1.0	3.0	3.0	4.0	2.5
pool	-	-	-	-	-	-	3.0	3.0	2.5	3.0
inorganic substrate composition[2]										
bedrock	-	-	-	-	-	-	-	-	-	-
boulder (>256 mm)	10	0	10	5	-	5	5	5	1	-
cobble (64-256 mm)	75	95	70	75	10	20	5	10	2	10
gravel (2-64 mm)	15	5	20	20	80	50	40	5	40	60
sand (0.06-2 mm)	-	-	-	-	10	25	45	60	50	30
silt (0.004-0.006 mm)	-	-	-	-	-	-	5	20	7	
clay (<0.004 mm)	-	-	-	-	-	-	-	-	-	-
organic substrate composition[2]										
detritus[3]	5	5	5	5	5	5	20	5	15	5
aquatic macrophytes (total)	50	100	50	100	100	80	30	70	60	100
filamentous algae	50	100	50	20	95	20	30	25	60	-
water lilies (Nymphaea, Nuphar)	-	-	-	-	-	-	-	50	-	-
pondweeds (Potamogeton spp) [4]	-	-	40	80	5	80	-	25	-	100
moss	-	-	-	-	5	-	5	-	2	-
waterweed (Elodea canadensis)	-	-	25	5	25	5	25	5	25	5
tidal influence	no	no	no	no	no	no	yes	yes	yes	yes

(1) stable = minimal evidence of erosion or bank failure
(3) logs, wood, coarse particulate organic matter
(2) percent coverage
(4) *Potamogeton richardsonii* at stn 5 and narrow-leaved species at the other stations.

Observed instream features changed slightly from previous years, mainly as a function of altered flows. Spring flows were apparently substantial with pronounced peaks, resulting in apparent wash-out of fine materials and even some gravel at upstream stations, with deposition at downstream stations. Flows then subsided for the summer, resulting in less active stream area, lower water velocity, and greater plant build-up. The August sampling represented the first true low flow sampling in this program thus far.

Filamentous algal growth was more abundant in 2002. Differences from 2001 were noted in June and August 2002 except at Station 1 in June (Table 1). Pondweed and waterweed also showed an increase in abundance during the August 2002 sampling period when compared with the previous year's data. Some shifts in apparent habitat type (pool-riffle-run) were recorded, mainly as a function of lower flows. These differences can be attributed to differential rainfall when comparing results from 2001 to 2002. As in previous years, stations 4 and 5 were evidently influenced by tidal activity (Table 1), as indicated by the presence of intertidal organisms such as cumaceans, spionid and capatellid polychaetes.

Average stream depth in 2002 broadly followed the 2000 and 2001 observations for June but differed in August 2002. Stream width for June 2002 was similar to previous years but also differed in August 2002 when compared to previous observations. The stream width was much narrower and the depth was generally lower in August 2002, likely due to the limited rainfall during that month (Table 1). Tide influenced stream depth at the downstream sites during sampling, with evident water level changes during data collection at stations 4 and 5.

Inorganic substrates were generally coarser at the upstream sites (Stations 1 and 2) in 2002 and progressively decreased in mean particle size in the downstream direction (Table 1), as in past years. Fine-grained substrate such as silt was observed only at the most downstream stations (4 and 5). However, presence of relatively coarse substrate (large gravel, cobble) was higher in June 2002 than June 2001 at stations 3, 4 and 5. It is possible that high rainfalls in June 2002 caused flooding that flushed fine sediments and loosened gravel in the upstream reach. This gravel, in turn, settled out as flow decreased due to widening of the river downstream. A more rigorous flow study would be necessary to better estimate particle transport patterns in the lower Mill River.

Quantity of detritus (e.g., logs, wood, leaf litter) remained at the relatively low levels of 2001 and were slightly higher in June 2002 when compared with that found in August of the same year. All stations had identical percentages of detritus in August 2002. Stations 4 and 5 had the greatest amount of detritus in June 2002 but the relative amount was minimal. General amounts of detritus, both fine and coarse, appeared to be sufficient to support abundant populations of macroinvertebrates at all stations.

Living vegetation was more abundant in 2002 than 2001. Forms tolerant of high flow such as attached moss and filamentous green algae (Chlorophyta: Chlorophyceae) comprised the majority of the vegetation at the upstream stations (1 and 2), but presence of rooted macrophytes (mostly narrow-leaved pondweeds) was heavier in 2002 than 2001. The greatest difference was observed in filamentous algal abundance. There was definite increase in filamentous algae at Station 3, 4 and 5 in June 2002 and at all stations in August 2002 when compared to the 2001 dataset. As in previous years, abundance of green algae decreased from spring to mid-summer. Waterlilies (*Nymphaea* sp.), a freshwater species that prefer low-flowing to lentic waters, were rarely observed in 2002. Waterweed (*Elodea canadensis*) was observed at all but station 1 in June 2002 but was uncommon in August 2002. All the taxa of vascular plants encountered in the lower Mill River were common taxa, tolerant of conditions such as low light, high nutrients, and salinity gradients (Crow and Hellquist 1980). Total plant coverage at the sites was within the typical ranges observed for temperate lotic systems (Allan 1995), although the increase over past years' observations was evident.

In general, habitat structure was suitable for macroinvertebrates at all stations. Substrate structural complexity (i.e., spatial heterogeneity) provides a diverse habitat for invertebrates, creating "niches" dominated by different food resources and hence invertebrate species, and/or providing crevices that protect invertebrates from predation or dislodgement by strong currents (Hixon & Menge 1991; Allan 1995). Macrophytes also contribute to increased spatial heterogeneity by providing a substrate rich in food resources (epiphytic algae and detritus covering the plants) (Diehl & Kornijów 1998). Physical substrate (cobble and gravel substrate) and/or macrophyte cover was sufficient to potentially support a rich and diverse macroinvertebrate community at all stations except station 4, where the waterlily-dominated vegetation did not appear to provide a sufficiently complex habitat to compensate for the flat, sand-dominated physical substrate. It is also important to note that purple loosestrife opportunistically inhabited dried area of the riverbed in August 2002. This was not noted in 2001 because the flow over the spillway was much greater, and was not recorded in the habitat assessment for 2002 because the affected areas were dry (not part of flowing stream).

Selected water quality parameters were assessed in 2002 (Table 2). Assessed water quality was generally similar over the four study years, with spatial and temporal variability as might be expected in this area of variable hydrology and loading. Water temperature remained comparable to temperatures observed in previous years, ranged between 19-30 ºC (Table 2), and varied only slightly between stations within the same month. Water temperature was higher in August 2002 than in June 2002 as expected. Dissolved oxygen was always within the life-supporting range for most lotic fauna (Table 2). Decreasing oxygen levels with increasing tidal influence were observed in a separate study (CH2M Hill 2001), but not in the 2002 data.

Specific conductivity was comparable between stations in June 2002, but was considerably higher at stations 4 and 5 in August. Saltwater influence from the most recent tide is likely responsible. Whether this was a function of the timing of sampling or greater saltwater intrusion under low flows is not known.

A slight increase in turbidity from June to August 2002 (Table 2) was observed and is probably induced by the desiccation of the habitat and narrower stream channel. Turbidity remained low (with values <5 NTU) in June 2002. Turbidity in August 2002 was highest at Station 5 and all but station 3 had values greater than 5 NTU.

As in previous years, pH in 2002 was circumneutral to slightly basic (Table 2). However, pH was relatively high in August 2002, an effect that might be attributed to increased algal influence. Even so, pH remained within the life-compatible 4.5 – 9.5 range for most aquatic biota (Wetzel 2001b).

Table 2. Water quality at the sampling locations, summer 2002.

parameter	station 1 17 Jun	station 1 19 Aug
water temperature (°C)	19.5	26.7
dissolved oxygen (mg/l)	9.2	5.7
dissolved oxygen (% saturation)	101	71
specific conductivity (μS/cm)	193	244
turbidity (NTU)	1.56	5.21
pH (SU)	7.2	8.4

parameter	station 2 17 Jun	station 2 19 Aug
water temperature (°C)	19.4	26.4
dissolved oxygen (mg/l)	9.3	8.0
dissolved oxygen (% saturation)	102	99
specific conductivity (μS/cm)	193	241
turbidity (NTU)	1.99	7.80
pH (SU)	7.7	8.81

parameter	station 3 17 Jun	station 3 19 Aug
water temperature (°C)	19.4	26.7
dissolved oxygen (mg/l)	9.2	5.9
dissolved oxygen (% saturation)	100	73
specific conductivity (μS/cm)	194	245
turbidity (NTU)	1.23	4.02
pH (SU)	7.7	8.2

parameter	station 4 17 Jun	station 4 19 Aug
water temperature (°C)	20.4	30.2
dissolved oxygen (mg/l)	9.4	8.5
dissolved oxygen (% saturation)	104	117
specific conductivity (μS/cm)	195	7013
turbidity (NTU)	3.16	8.42
pH (SU)	7.9	8.29

parameter	station 5 17 Jun	station 5 19 Aug
water temperature (°C)	21.5	28.8
dissolved oxygen (mg/l)	9.5	6.6
dissolved oxygen (% saturation)	108	87.4
specific conductivity (μS/cm)	198	7333
turbidity (NTU)	2.00	10.40
pH (SU)	7.9	8.1

Macroinvertebrates

Total abundance of invertebrates observed in June 2002 was significantly greater than in June 2001 with $p \leq 0.05$ in June (chi square test: $X^2=1967.14$, $d.f.=1$). Abundance of macroinvertebrates observed in August 2002 when compared to those observed in August 2001 were not significantly different with $p \geq 0.05$ (chi square: $d.f.=1$, $X^2=1.48$, $p=0.23$). The increased macroinvertebrate abundance in June 2002 could be attributed to increased vegetative growth observed during this sampling period. Increases in vegetation provide more niche space for individuals and species. However, it is important to recognize that some of the differences in diversity and abundance calculations could be attributed to individual sorting techniques. Invertebrate abundance was lowest at Station 4 in August 2002, similar to the results observed for August 2001. A complete taxonomic and ecological (feeding) characterization of the invertebrate taxa found is presented in Tables 4 and 5.

General macroinvertebrate assemblage structure and patterns were similar in all four years. For example, the three upstream stations (sites 1, 2 and 3) exhibited markedly higher invertebrate abundance, taxonomic richness, and taxonomic diversity than the two downstream sites (stations 4 and 5) (Table 3; Figures 2 and 3). The differences were more dramatic in 2002 than 2001.

Taxonomic richness, or number of taxa (*S*), was higher at stations 1, 2, 3 and 5 in 2002 than in 2001 (Figure 3) for June sampling. Station 4 had a richness value of 11 in 2001 but a value of 9 in 2002. This may be due to the random sampling nature of the project. However, richness was lower in August at all stations in 2002 than 2001. This could be attributed to the fact that the August 2002 sampling was conducted during a period of high heat and lack of rainfall. The lack of rainfall can cause stress and this could account for lower taxonomic richness values observed in August 2002 when compared with those found in 2001. As in 2001, taxonomic richness was higher at the upstream than downstream stations.

Taxonomic diversity (*H'*) at the upstream sites (Stations 1, 2 and 3) for June was higher in 2002 than 2001. Taxonomic diversity at Station 4 was slightly lower in June than in 2001 and the diversities at Station 5 were approximately equal.

Table 3. Number of individual macroinvertebrate (by taxa) at each sampling site, June and August 2002. Sampling time is also reported. Location of sampling sites is in Figure 1. For comparison purposes to the 2001 data set a blue color indicates an increase in abundance from 2001; red indicates a decrease in abundance from 2001. A hyphen indicates no difference or no individuals. Statistically significant differences were not tested for individual taxonomic abundance. June total=5,294; August total=3,024

	17 June										19 August									
	sites										sites									
	1		2		3		4		5		1		2		3		4		5	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Time Sampled	11:37	11:50	11:02	11:20	12:38	12:45	13:16	13:30	13:45	14:00	15:30	16:00	16:15	16:30	16:50	17:10	17:30	17:55	18:20	18:40
Taxon																				
Hydra sp.	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Dugesia sp.	0	4	0	16	0	0	4	0	4	-	0	0	0	0	0	0	-	0	0	-
Amnic. limosa	0	0	0	0	0	0	-	-	-	-	0	0	0	0	0	0	-	-	-	0
Physa sp.	0	0	4	28	-	4	0	-	-	-	-	-	8	8	-	-	-	-	-	0
Gyralus parvus	0	8	0	4	8	8	0	0	-	-	4	0	0	8	0	12	-	-	-	0
G. circumstr.	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-
Lymn. colum.	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	-	-	-
Pleurocera sp.	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-
Pomatiopsis sp.	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	-
Ferr. rivularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-
Helisoma sp.	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-	-
Bithynia tentaulata	12	76	112	76	288	72	-	-	12	4	44	-	12	28	64	136	8	-	12	12
Sphaeriidae	-	-	-	-	32	0	8	8	-	28	4	-	0	-	4	8	-	12	-	-
Gl. complanata	-	-	-	-	-	-	0	-	-	-	-	-	-	0	-	-	-	0	-	-
Oligochaeta	132	286	16	32	60	232	264	172	304	100	16	4	-	-	-	-	0	16	24	4
Marenzellaria viridis	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-
Heteromastus filiformis	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Ampheretidae	-	-	-	-	-	-	-	-	-	4	4	-	-	-	-	-	-	-	-	-
Crangonyx sp.	-	0	0	0	0	0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Lirceus sp.	0	0	0	0	0	0	-	-	-	-	-	-	0	-	-	-	-	-	-	-
Gammarus fasciatus	64	88	100	315	268	220	4	0	0	37	92	24	52	40	8	8	0	-	20	12
Gammarus sp.	-	-	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Almyracuma proximoculi	-	-	-	-	-	-	-	-	8	20	-	-	-	-	-	-	-	-	4	-
Asellus communis	-	-	4	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ischnura sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Enallagma sp.	-	-	-	-	-	-	-	-	-	-	-	-	60	8	-	-	-	-	-	-
Caenis sp.	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Isonychia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Ephemerellidae.	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triaenodes sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-
Ceraclea sp.	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	-	-	0	0
Mystacides sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	0	0
Macrostemum sp.	-	0	-	0	-	-	-	-	-	-	0	0	0	0	0	-	-	-	-	-
Hydropsyche sp.	20	0	16	20	-	-	-	0	-	-	0	228	16	24	-	-	-	-	-	-
Psychomia sp.	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxyethira sp.	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-
Rossiana sp.	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	0
Brachycentrus sp.	4	8	16	36	-	4	8	12	-	-	4	60	-	0	4	-	-	-	-	-
Micrasema sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-
Limnephilidae	-	-	-	-	-	-	-	0	-	-	-	-	-	-	0	0	-	-	0	0
Berosus sp.	-	-	8	4	4	0	-	-	-	-	-	0	-	0	-	-	-	-	4	0
Psephenidae	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	8
Ceratopognidae	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemerodromia sp.	16	4	80	32	16	60	16	-	8	-	20	28	8	12	-	4	4	-	-	4
Simulium sp.	0	0		8	-	-	-	-	-	-	0	0	0	0	-	-	-	-	-	-
Diptera sp.	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
Arrenuroidea	-	-	16	4	-	4	-	-	-	-	-	-	-	4	-	-	-	-	-	-
Chironomidae	52	56	320	228	80	280	68	68	20	40	152	1100	184	96	76	64	28	4	52	40
TOTAL	**300**	**530**	**756**	**827**	**756**	**884**	**372**	**272**	**360**	**237**	**340**	**1444**	**340**	**236**	**156**	**232**	**48**	**32**	**116**	**80**

Figure 2. Number of individuals per sampling for selected common taxa in June **(left)** and August 2001 **(right)**. Gam: *Gammarus fasciatus*.; Chir: Chironomidae sp.; Bithy: *Bithynia tentaculata* sp.; Heme: *Hemerodromia* sp.; Gyral: *Gyralus parvus*. Location of sampling sites is in Figure 1.

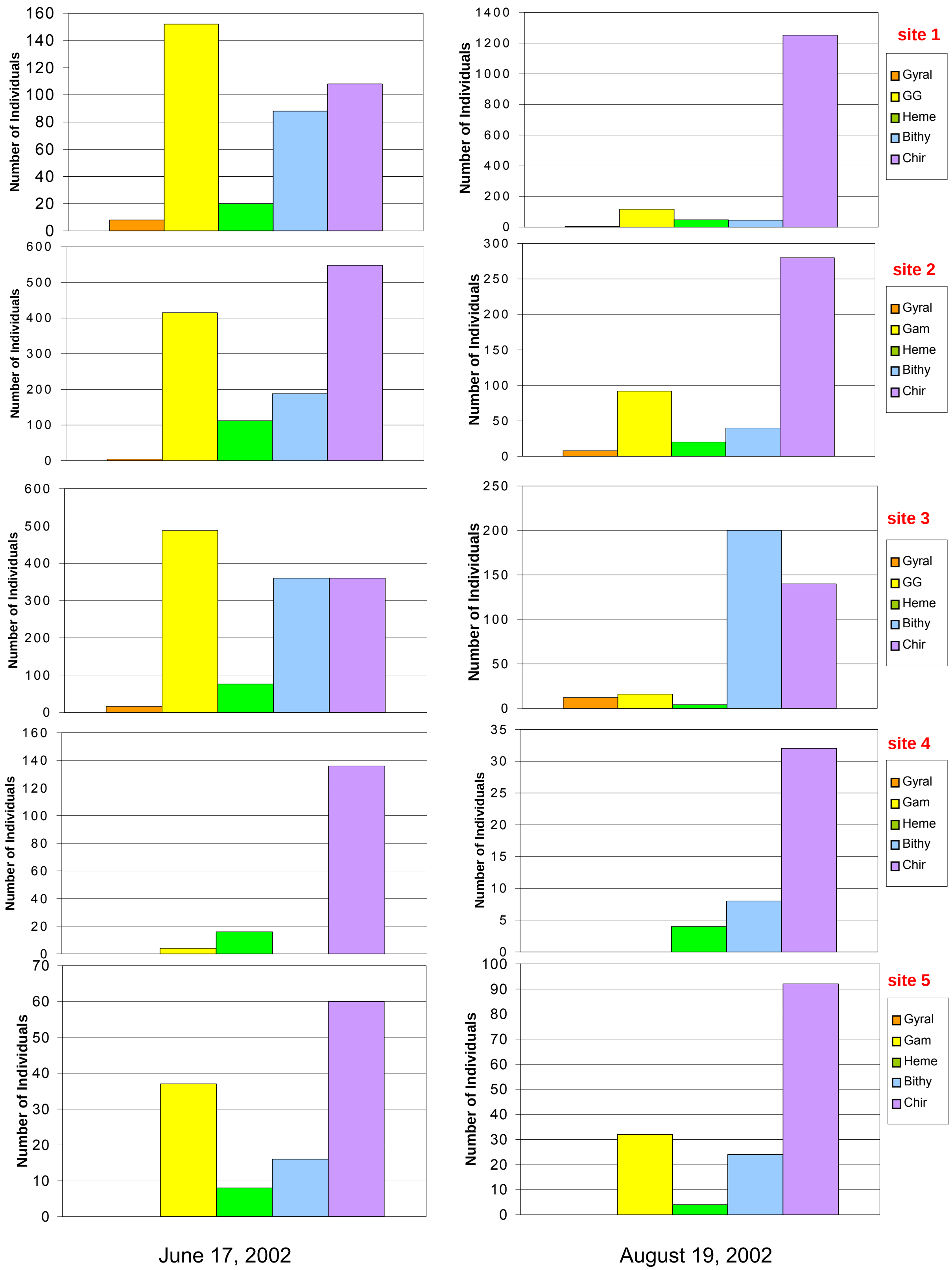


Figure 3. Macroinvertebrate taxonomic richness (*S*), diversity (*H'*) and evenness (*J'*) in June and August 2001. Location of sampling sites is in Figure 1.

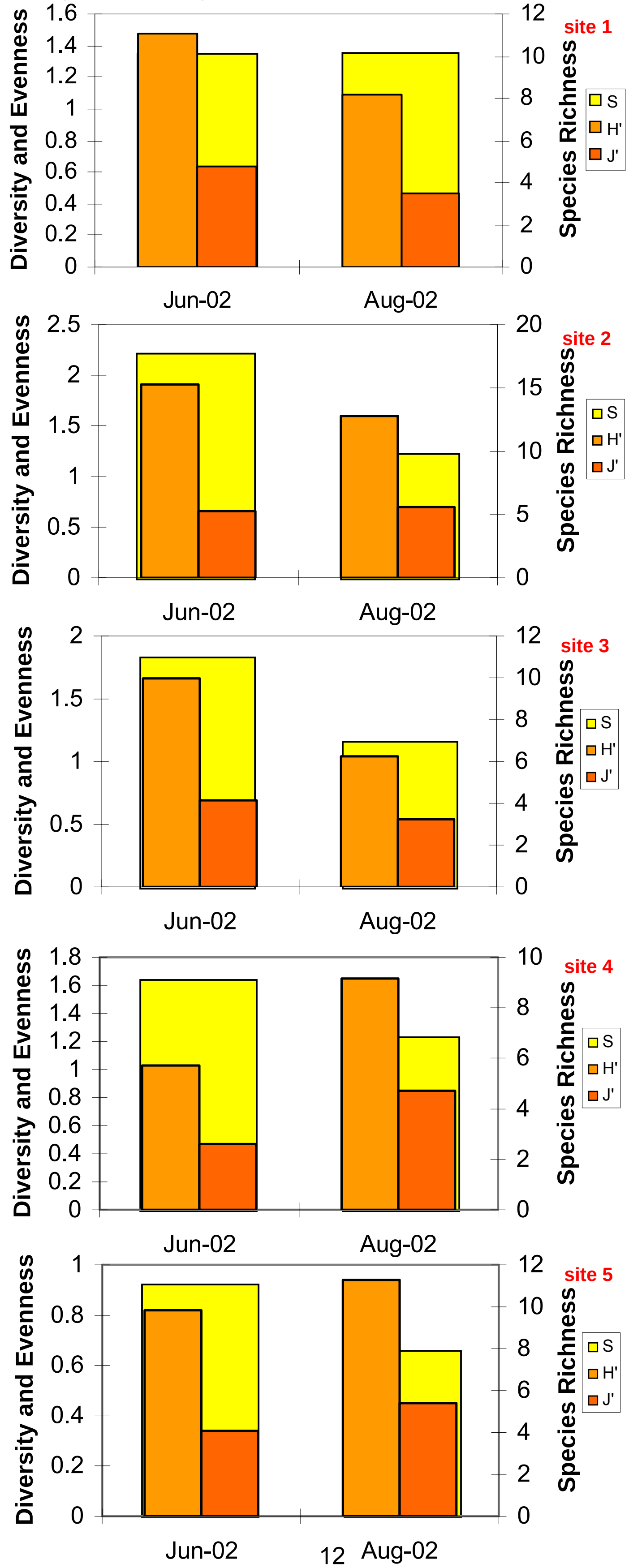


Table 4. Macroinvertebrate taxonomic characterization for 2002 sampling period.

Phylum or major taxonomic group	Class or subclass	order, subclass, or superfamily	family or superfamily	taxon	present on 17 Jun	present on 19 Aug
Platyhelminthes	Turbellaria	Tricladida	Dugesiidae	*Dugesia* sp.	x	
Mollusca	Gastropoda	Pulmonata	Physidae	*Physa* sp.	x	x
Mollusca	Gastropoda	Pulmonata	Planorbidae	*Gyraulus parvus*	x	x
Mollusca	Gastropoda	Pulmonata	Planorbidae	*Helisoma* sp.	x	
Mollusca	Gastropoda	Prosobranchia	Bithyniidae	*Bithynia tentaculata*	x	x
Mollusca	Bivalvia	Corbiculacea	Spheriidae	Sphaeriidae	x	x
Annelida	Oligochaeta	Tubificinae	Tubificidae	Oligochaeta	x	x
Annelida	Polychaeta	Spioninae	Spionidae	*Marenzellaria viridis*	x	
Annelida	Polychaeta	-	Capitellidae	*Heteromastus filiformis*	x	
Annelida	Polychaeta	-	Ampheretidae	*Ampheretidae*	x	x
Crustacea	Malacostraca	Amphipoda	Gammaridae	*Gammarus fasciatus*	x	x
Crustacea	Malacostraca	Amphipoda	Gammaridae	*Gammarus* sp.	x	
Crustacea	Malacostraca	Isopoda	Asellidae	*Asellus communis*	x	
Crustacea	Malacostraca	Cumacea	Nannastacidae	*Almyracuma proximoculi*	x	x
Uniramia	Insecta	Odonata	Coenagrionidae	*Enallagma* sp.		x
Uniramia	Insecta	Ephemeroptera	Ephemerellidae	Ephemerellid	x	
Uniramia	Insecta	Trichoptera	Hydropsychidae	*Hydropsyche* sp.	x	x
Uniramia	Insecta	Trichoptera	Brachycentridae	*Brachycentrus* sp.	x	x
Uniramia	Insecta	Tricopthera	Brachycentridae	*Micrasema* sp.		x
Uniramia	Insecta	Coleoptera	Hydrophilidae	*Berosus* sp.	x	x
Uniramia	Insecta	Coleoptera	Psephenidae	Psephenidae		x
Uniramia	Insecta	Coleoptera	Ceratopognidae	Ceratopognidae	x	
Uniramia	Insecta	Diptera	Empididae	*Hemerodromia*	x	x
Uniramia	Insecta	Diptera	Simuliidae	*Simulium*	x	
Uniramia	Insecta	Diptera	Chironomidae	Chironomidae	x	x
Uniramia	Insecta	Diptera	-	Diptera	x	
Arachnica	Acari	Parasitengona	Arrenuroidea	Arrenuroidea	x	x

Table 5. Macroinvertebrate ecological (feeding) characterization. Primary (main) and secondary feeding categories are given for facultative predators and generalists (herbivores and/or detritivores). Feeding modality refers to how the animals obtain their food (see note on bottom). Feeding information was obtained mainly from Merritt & Cummins (1996), Thorp & Covich (1991), and ENSR staff personal observations.

taxon	General	primary	secondary	feeding modality[1]
Dugesia	facultative predator	predator	detritivore	engulfer / scraper
Physa sp.	Generalist	herbivore	detritivore	scraper
Gyraulus parvus	Generalist	detritivore	herbivore	scraper
Helisoma sp.	Generalist	detritivore	herbivore	scraper
Bithynia tentaculata	Generalist	detritivore	herbivore	scraper
Sphaeriidae	Detritivore	detritivore	-	filter feeder
Oligochaeta	Detritivore	detritivore	-	collector
Marenzellaria viridis	Generalist	Detritivore	-	filter feeder
Heteromastus filiformis	Generalist	Detritivore	-	head down deposit feeder
Ampheretidae	Generalist	Detritivore	-	deposit feeder
Gammarus fasciatus	Generalist	detritivore	herbivore	shredder
Gammarus sp.	Generalist	detritivore	herbivore	shredder
Asellus communis	Detritivore	detritivore	-	shredder
Almyracuma proximoculi	Detritivore	Detritivore	-	shredder
Enallagma sp.	Predator	predator	-	engulfer
Ephemerellid	Predator	predator	-	engulfer
Hydropsyche sp.	Generalist	detritivore	herbivore	filter feeder
Brachycentrus sp.	Generalist	detritivore	herbivore	collector / filter feeder
Micrasema sp.	Generalist	detritivore	herbivore	collector/filter feeder
Berosus sp.	Generalist	predator	detritivore	piercer / collector
Psephenidae	Obligate predator	predator	-	engulfer
Ceratopognidae	Obligate predator	predator	-	engulfer
Hemerodromia	Detritivore	detritivore	-	collector
Simulium	Generalist	detritivore	herbivore	filter feeder
Chironomidae	Generalist	herbivore	detritivore	shredder
Diptera	Generalist	predator	detritivore	piercer / collector
Arrenuroidea	Parasite	parasite	parasite	parasite

[1] predator: engulfer and/or piercer
shredder: coarse food cut into smaller particles
collector: fine food particles gathered from substrate
scraper: coarse food scrubbed off substrate
filter feeder: suspended particles captured from water

Higher diversities seen at the upstream locations in 2002 could be caused by increased abundance of vegetation cover that creates more spatial heterogeneity. In August 2002, all stations except Station 4 had lower diversities than in 2001. Again, the stress to the stream environment caused by the dry, hot weather and little rainfall in August 2002 may explain the differences in diversity.

Evenness (*J'*) remained at comparable, relatively low levels in 2002 when compared with evenness calculated in 2001 (Figure 3). Low evenness was related to numerical dominance by a few taxa in both years, but given the presence of ephemeropterans and trichopterans, two groups that are considered intolerant to degraded water quality conditions, the low evenness may not be entirely a function of degraded habitat.

Most of the common taxa observed in 2001 were also encountered in 2002. Taxonomic resolution was lowest in 1998 and was improved as of 2000 by design. Taxa observed in 2001 but not in 2002 are identified in Table 1 with a red 0 to indicate that the abundance of these taxa decreased in 2002 when compared with the 2001 dataset. Taxa identified in 2002 that were rare included the polychaetes *Marenzellaria viridis*, *Heteromastus filiformis*, the cumacean *Almyracuma proximoculi*, the isopod *Asellus communis*, and the insects *Micrasema* sp., Ceratopognidae sp., and Psephenidae sp. Rare taxa tend to be patchily distributed, and patchiness may be exacerbated by spatial heterogeneity. Therefore, absence of such rare taxa in some samples or years may not mean that the taxa do not occur in the lower Mill River system.

Differences in macroinvertebrate taxonomic composition between the upstream (sites 1 through 3) and downstream stations (sites 4 and 5) may be ascribed mostly to differences in physical habitat and salinity exposure. As in 2001, macroinvertebrate assemblages in the upstream stations were more indicative of riffle habitat and coarse substrates, and included several filter-feeding and collector taxa that feed on detritus (e.g., Hydropsychidae, Ephemerellidae, *Physa* sp. and the dipteran *Simulium*). Chironomids were found in much greater abundances in the upstream stations than in the downstream stations 4 and 5. Taxa that can tolerate influxes of marine water were found only at stations 4 and 5. This includes one species of cumacean, three species of polychaetes, the insect Psephenidae, plus several taxa abundant in all stations such as oligochaetes, *Gammarus fasciatus,* and the gastropod *Bithynia tentaculata*. Freshwater invertebrate tolerance to salinity is not well known, but some of the taxa found in the lower Mill River (e.g., scuds, damselflies, chironomid midges, beetles, and pulmonate snails) are found in relatively high numbers in moderately saline lakes (Colburn 1988; Alcocer et al. 1998).

In general, the macroinvertebrate assemblages observed in June 2002 were indicative of moderately healthy stream communities, as in 1998, 2000, and 2001 (ENSR 1998, 2000, 2001). However, the drier habitat observed in August 2002 could be a factor affecting abundance, richness, and taxonomic diversity of benthic macrofauna. The taxa collected at the five stations located along the Mill River may be commonly found in a range of environments (e.g., scuds, prosobranch snails, caddisflies, mayflies). Most taxa found were typical of urban freshwater habitats (Walsh et al. 2001), where water quality impacts are common. Compared to 2001 values, diversity increased in June 2002 but declined in August, possibly as a consequence of many environmental factors, including the desiccation of the stream during the dry summer months, changes in water quality, altered food abundance and quality, and predation effects.

Midges (Diptera Chironomidae) can be found in a variety of freshwater habitats (Wetzel 2001c), but their dominance in a community is often regarded as a sign of degraded conditions. Midges dominated at the upstream sites (stations 1, 2, and 3) in 2002 (Figure 2), similar to the results of 2001. Amphipods (*Gammarus* spp.) were highly abundant at the upstream stations in both June and August 2002, similar to the pattern observed in 2001. However, abundances were much greater in 2002 than in 2001. The less common scud *Crangonyx* that was present in 2001 was not found in 2002. This pattern is consistent with the observed decline in flow in August 2002, but may not be entirely a function of that decline.

Snails (Mollusca, Gastropoda) were represented by several taxa, most of which are tolerant of organic pollution and degraded conditions (Brown 1991). Limpets (*Ferrissia rivularis*, which prefer fast-flowing and clean habitats according to Pip 1986) were present but rare at station 3 in 2001 and absent in 2002. *Bithynia tentaculata* was not found in 2001 and was found at nearly all the stations sampled in 2002. This species of gastropod may be proliferating because of increased vegetation found in the upstream stations, or this may be a taxonomic identification issue (a similar hyrobiid snail was present in 2001).

Predators (odonates and beetles) were represented by five taxa and had relatively low abundance (Table 3). Number of predator taxa and individuals were lower in 2001 than 2002. Data from the 2002 survey suggested that food availability in the lower Mill River was sufficient to support a relatively complex invertebrate food web, even if water quality is suboptimal for invertebrates (ENSR 2000).

CONCLUSIONS

The macroinvertebrate assemblage in the lower Mill River is the product of several factors acting simultaneously. Flow can be a major determinant of invertebrate assemblage structure (e.g., Brunke et al. 2001), influencing invertebrates directly or by altering physical instream habitat and physico-chemical characteristics such as temperature, oxygen, pH, and conductivity (Sabo et al. 1999). Predicted lower flow from the Lake Whitney dam as a result of increasing withdrawal for human use may affect the composition of the macroinvertebrate community as a function of food resource changes and feeding group shifts. Density of the scud *Crangonyx sp.* also may be reduced by lower flow regimes, while the closely related but slow-water taxon *Gammarus* may increase (Beckett et al. 1998). However, effects may be highly localized in time and space. Any impacts relating to flow would be expected only during withdrawals that coincide with low flow periods, not from expected withdrawal during higher flows.

Reduced flow may decrease invertebrate density and diversity (Gørtz 1998; Brunke et al. 2001), but flow interacts closely with the physical structure of the habitat. Streams with relatively low flow but high degree of habitat heterogeneity (coarse detritus, rocks, submerged vegetation) may still support high invertebrate density, taxonomic richness and diversity (Brunke et al. 2001). Increased vegetation cover may be expected at lower flow regimes, thus counterbalancing (at least in part) the potentially negative effects of decreased flow by increasing substrate heterogeneity. Though some changes in densities and relative abundances may occur, large scale changes in invertebrate community features in the lower Mill River are not expected after the withdrawal from Lake Whitney commences. Furthermore, relatively rapid response of invertebrate communities suggests that recovery will be swift when higher flows resume after a drought period.

Effects of increased salinity (possibly brought about by lower flow, desiccation in late summer months, and/or any future alteration or removal of the downstream tide gates) on the lower Mill River invertebrate assemblages are difficult to predict, but would seem likely to be more severe than minor changes in flow. Most of the taxa found in the 1998, 2000, 2001 and 2002 surveys may withstand small increases in salinity, with invertebrate communities shaped more by physical habitat characteristics than fluctuations in salinity (Alcocer et al. 1998). However, effects of possible tide-related bursts in salinity, exacerbated by lower flow or removal of tide gates, could shift the community to a taxa-poor, low-diversity assemblage dominated by high salinity tolerant taxa (Wolfram et al. 1999). The current community at stations 4 and 5, where salinity exposure is periodically high, already exhibit this condition to a large extent. However, the upstream portion of the lower Mill River (e.g., stations 1 through 3) appears unlikely to be significantly affected by tide-driven salinity bursts, because of its higher elevation.

As was the conclusion from the 2001 survey, the data collected in 2002 suggest that alteration of flow associated with reactivation of Lake Whitney as a water supply appears to be only a minor potential influence on the lower Mill River. Also, and on a larger-scale basis, projected lower flow in the lower Mill River may not influence the downstream New Haven Harbor, since the lower Mill River's contribution to harbor hydrology and water chemistry is marginal (Rozan & Benoit 2001). However, 2002 did provide data for the lowest flow period monitored to date, and some changes are evident that may be related to the lower August flows. Additional data from continuing monitoring will be necessary to more accurately determine how changes in flow will affect benthic macroinvertebrate communities in the lower Mill River.

LITERATURE CITED

Alcocer J., E. Escobar, A. Lugo, & L. Peralta, 1998. Littoral benthos of the saline crater lakes of the basin of Oriental, Mexico. INTERNATIONAL JOURNAL OF SALT LAKE RESEARCH 7: 87-108

Allan J. D., 1995. *Stream Ecology – Structure and Function of Running Waters*. Chapman & Hall, London, UK.

Barbour M. T., J. Gerritsen, B. D. Snyder, & J. B. Stribling, 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. Second edition. EPA 841-B-99-002. USEPA, Office of Water. Washington, DC.

Beckett D. C., P. A. Lewis, & J. H. Green, 1998. Where have all the *Crangonyx* gone? The disappearance of the amphipod *Crangonyx pseudogracilis*, and subsequent appearance of *Gammarus* nr. *fasciatus*, in the Ohio River. THE AMERICAN MIDLAND NATURALIST 139: 201-209

Brown K. M., 1991. Mollusca: Gastropoda. Pp. 285-314 in: *Ecology and Classification of North American Freshwater Invertebrates*, J. H. Thorp & A. P. Covich editors. Academic Press, San Diego, CA.

Brunke M., A. Hoffman, & M. Pusch, 2001. Use of mesohabitat specific relationships between flow velocity and river discharge to assess invertebrate minimum flow requirements. REGULATED RIVERS: RESEARCH & MANAGEMENT 17: 667-676

CH2M Hill, 2001. 2001 monitoring of Mill River dissolved oxygen and salinity – Hamden and New Haven, CT. Report for the SCCRWA.

CH2M Hill, 2002. 2002 Water Quality Monitoring, Mill River, Hamden and New Haven, CT. Report for the SCCRWA.

Colburn E. A., 1988. Factors influencing species diversity in saline waters of Death Valley, USA. HYDROBIOLOGIA 158: 215-226

Crow G. E., and C. B. Hellquist, 1980. Aquatic Vascular Plants of New England. Part 1 through 8. Series of bulletins published by the New Hampshire Agricultural Experiment Station, University of New Hampshire. Durham, NH.

Diehl S., & R. Kornijów, 1998. Influence of submerged macrophytes on trophic interactions among fish and macroinvertebrates. Pp. 24-46 in: *The Structuring Role of Submerged Macrophytes in Lakes*; E. Jeppesen, Ma. Søndergaard, Mo. Søndergaard, and K. Christoffersen Editors. Springer-Verlag, New York, NY.

ENSR, 1998. Aquatic biological assessment of the Lower Mill River – Hamden, Connecticut. Final Report to the SCCRWA, 1998.

ENSR, 2000. Benthic biological assessment of the Lower Mill River – Hamden / New Haven (CT). Final report to the SCCRWA, 2000.

ENSR, 2001. Benthic biological assessment of the Lower Mill River – Hamden / New Haven (CT). Final report to the SCCRWA, 2001.

Gørtz P., 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS 8: 115-130

Hixon M. A., & B. A. Menge, 1991. Species diversity: prey refuges modify the interactive effects of predation and competiiton. THEORETICAL POPULATION BIOLOGY 39: 178-200

Lombardo P., 1997. Predation by *Enallagma* nymphs (Odonata, Zygoptera) under different conditions of spatial heterogeneity. HYDROBIOLOGIA 356: 1-9

Merritt R. W., & K. W. Cummins (editors), 1996. *An Introduction to the Aquatic Insects of North America*, third Edition. Kendall/Hunt Publishing, Dubuque, IA.

Peckarsky B. K., P. R. Fraissinet, M. A. Penton, & D. J. Conklin Jr., 1993. *Freshwater Macroinvertebrates of Northeastern North America*. Cornell Univ. Press, Ithaca, NY.

Pip E., 1986. The ecology of freshwater gastropods in the central Canadian region. NAUTILUS 100: 56-66

Rozan T. F., & G. Benoit, 2001. Mass balance of heavy metals in New Haven Harbor, Connecticut: predominance of nonpoint sources. LIMNOLOGY AND OCEANOGRAPHY 46: 2032-2049

Sabo M. J., C. F. Bryan, W. E. Kelso, & D. A. Rutherford, 1999. Hydrology and aquatic habitat characteristics of a riverine swamp: I. Influence of flow on temperature and water chemistry. REGULATED RIVERS: RESEARCH & MANAGEMENT 15: 505-523

Thorp J. H., & A. P. Covich (editors), 1991. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press, San Diego, CA.

Walsh C. J., A. K. Sharpe, P. F. Breen, & J. A. Sonneman, 2001. Effects of urbanization on streams of the Melbourne region, Victoria, Australia. I. Benthic macroinvertebrate communities. FRESHWATER BIOLOGY 46: 535-551

Wetzel R. G., 2001a. Oxygen. Chapter 9 in: *Limnology - Lake and River Ecosystems*, 3rd edition. Academic Press, San Diego, CA.

Wetzel R. G., 2001b. The inorganic carbon complex. Chapter 11 in: *Limnology - Lake and River Ecosystems*, 3rd edition. Academic Press, San Diego, CA.

Wetzel R. G., 2001c. Littoral and profundal benthic communities of lakes. Pp. 702-705 in: *Limnology - Lake and River Ecosystems*, 3rd edition. Academic Press, San Diego, CA.

Wolfram G., K. Donabaum, M. Schagerl, & V. A. Kowarc, 1999. The zoobenthic community of shallow salt pans in Austria – preliminary results on phenology and the impact of salinity on benthic invertebrates. HYDROBIOLOGIA 408/409: 193-202

Zar J. H., 1984. Indices of diversity. Pp. 32-36 in: *Biostatistical Analysis*, 2nd edition. Prentice Hall, Englewood Cliffs, NJ