ASSESSMENT OF BENTHIC MACROINVERTEBRATE COMMUNITIES IN RELATION TO REGULATED FLOWS IN THE DEERFIELD RIVER, MASSACHUSETTS

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Prepared for

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Boston, Massachusetts

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FINAL REPORT

Prepared for

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May 2007

EXECUTIVE SUMMARY

- The 2004-2008 Deerfield River Five-Year Action Plan identifies *as a priority action* the need to perform macroinvertebrate surveys of the mainstem Deerfield River to determine the potential impact on the river's ecology of fluctuating water levels created by hydroelectric projects. The Action Plan explains that concerns have been raised that the rapid changes in flow caused by hydropeaking create unstable habitats that may reduce the abundance and diversity of aquatic macroinvertebrates and fish and cites a current lack of data to properly evaluate these concerns. This study aimed to fill this critical information gap relating to the ecological health of the Deerfield River; the data will serve as a baseline of the status of the benthic community of this valuable resource to the region. The goal of this study was to determine whether differences in macroinvertebrate abundance and community structure occur between regulated sections of the Deerfield River and nearby unregulated river reaches.

- Macroinvertebrates were sampled from regulated reaches of the Deerfield River, as well as from unregulated reaches of multiple tributaries. Four regulated reaches were selected from immediately below Fife Brook Dam downriver to the town of Charlemont. The lower reaches of the North River and the Cold River in Massachusetts and the West Branch of the Deerfield River in Vermont, were each sampled as unregulated control reaches against which to compare biological conditions in the regulated reaches of the Deerfield River.

- Macroinvertebrate communities were sampled between July 26 and 29, and again between September 27 and 29, 2006 from each reach. Three replicate samples were collected from each reach during each sampling period. Physical data were collected, including water depth and velocity at each kick-net sampling location. Substrate composition of each sample reach was measured using Wolman pebble counts. Onset Water Temp Pro temperature loggers set to record water temperatures every 15 minutes were deployed in each reach during the July sampling episode and retrieved during the September sampling episode.

- Macroinvertebrate communities of the Deerfield River between Charlemont and the Fife Brook Dam, in relation to communities of Deerfield River tributaries with unmodified flow regimes, show an increasing divergence in community composition with closer proximity to the Fife Brook Dam. Community conditions immediately below Fife Brook dam, characterized by dominance by filter-feeding organisms and Chironomidae, and low abundance of mayflies and stoneflies, differed most from the tributary reaches. Mayfly abundance was low in the upper Deerfield River reaches in both July and September. A number of mayfly and stonefly taxa that occurred in all other reaches were absent from samples from the upper Deerfield River reaches, suggesting that either thermal or hydrologic modification of the upper reaches is precluding some taxa from occurring in these areas in the same numbers that they occur elsewhere. Temperature data collected during this study suggest that both diel and seasonal temperature regimes are altered by the Fife Brook reservoir and that these effects are ameliorated further downriver.

- The effects of Fife Brook dam and hydropeaking activities on macroinvertebrate communities inhabiting riffle habitat of the Deerfield River appear to be spatially limited. Differences in macroinvertebrate communities that appear to be related to proximity to Fife Brook dam were most pronounced immediately below the dam and at the above-Bridge-to-Nowhere reach located approximately 2.5 miles below Fife Brook dam. Metric analysis and multivariate analysis both suggested that community conditions were more similar to tributary conditions approximately seven miles below the Fife Brook dam, where the seasonal thermal regime was also more similar to that observed in the tributaries. Twelve miles below Fife Brook dam at the Charlemont sampling reach, macroinvertebrate community composition more closely resembled that of the tributaries than the upper mainstem reaches, suggesting that the conditions modifying communities upriver are abated in these lower reaches between Charlemont and the #4 dam.

- The patterns observed in this unreplicated study, although spatially related to proximity to the Fife Brook dam, can not be inferred to be directly or exclusively related to the current hydropeaking regime. Altered water temperatures, nutrient content, and food resources in the river below Fife Brook dam also potentially contribute to these observed patterns. Separating out the relative contribution of these potentially causative factors is beyond the scope of this study. These data should serve as a baseline for understanding conditions under the current river management regime. Continued monitoring of the benthic communities should help even better characterize these conditions in relation to the current range of environmental conditions created by the hydropeaking operations and can help quantify changes to the biology that may result from future modification of hydropeaking activities.

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ACKNOWLEDGMENTS

This study was funded with a grant from the Massachusetts Executive Office of Environmental Affairs (EOEA) with additional support provided by the Connecticut River Watershed Council and the Deerfield River Watershed Association. A number of persons were instrumental in the development of this project, including Marie-Francoise Walk and Robert May of the Deerfield River Watershed Association, and Peter Mitchell, John Fiorentino, and Robert Nuzzo with the Massachusetts Department of Environmental Protection (DEP). Volunteer field support was provided by Andrea Donlon of the Connecticut River Watershed Council, Marie-Francoise Walk, Robert May. Thanks also to Arthur Screpetis of DEP for technical support for the project and to John Clarkeson of EOEA for administration of the grant to support the work. ABR technician Robin Creamer sorted macroinvertebrate samples. Thanks also to J. Kelly Nolan of Watershed Assessment Associates for providing taxonomic quality control identification work.

INTRODUCTION

The Deerfield River drains approximately 665 mi^2 in Massachusetts and Vermont. The river and its tributaries support multiple and diverse uses, including rafting, canoeing and kayaking, fishing, and swimming, as well as development interests such as power production and flood control. The watershed is recognized as one of the cleanest and most undisturbed in Massachusetts. Because of its high gradient, the Deerfield supports nine dams used for hydropower generation. The Deerfield River Hydroelectric System has been nationally recognized for its environmental accomplishments, including flow releases to protect fish and waterfowl and purchase of land conservation easements (National Hydropower Association, 1999). A 1997 FERC hydro relicensing settlement established minimum flows in 12 miles of river that were previously bypassed and provided commitments for future fish passage facilities.

A study in the Deerfield River prior to the establishment of minimum flows demonstrated that variable streamflows modified the fish community composition in the river (Bain et al. 1988). Changes in water levels displaced shallow shoreline zones, forcing fish in those areas to relocate, stranding fish, or exposing trapped fish to predation. The Bain study focused on fish communities and examined the effects of low flows on fish and fish habitat. No studies have been conducted on the river following the establishment of minimum flows, yet it is likely that these protective flows have benefited the river’s ecology. However, the effects of fluctuating water levels, particularly artificially high flows created by hydropeaking, on the river’s ecology continue to concern resource managers, watershed groups, and area anglers.

The effects of pulsed high flows on benthic macroinvertebrate abundance and community structure are of particular concern, but have gone unexamined in the Deerfield River. Studies in other regions of the United States and in Europe have documented the deleterious effects of hydropeaking on the benthic ecology of rivers (e.g. Cereghino and Lavandier 1998, Bretschko and Moog 1990, Irvine 1985, Moog 1993). These and other studies have collectively shown that hydropeaking can reduce macroinvertebrate densities and biomass. However, the magnitude of these effects and the area over which they occur depend on a large number of factors and therefore vary among rivers, thereby making extrapolation with a high confidence to the Deerfield and other unstudied river systems difficult.

The current hydro operations on the river can result in daily discharge fluctuations by almost tenfold. These pulsed high flows may be detrimental to the river’s ecology by increasing water velocities to the extent that they interfere with use or colonization of the river bottom by macroinvertebrates that are more sensitive to high flows. Although most macroinvertebrates are equipped with physical or behavioral mechanisms to allow them to cope with high-flow events, regular pulsing of high flows during summer and fall, when such conditions would otherwise be uncommon, may interfere with macroinvertebrate life histories. Additionally, higher water velocities create greater potential for increased flushing of leaves, detritus and algae from the river, thereby reducing food source availability to most macroinvertebrates. As such, macroinvertebrate abundance, species richness, and community structure are all potentially at risk.

The 2004-2008 Deerfield River Five-Year Action Plan specifically identifies *as a priority action* the need to perform "aquatic macroinvertebrate surveys along portions of the mainstem Deerfield River to determine diversity and abundance, as well as overall habitat quality. Priority areas would include hydroelectric dam bypass reaches, as well as locations directly below hydroelectric projects that may be impacted by frequent fluctuating water levels created by hydropeaking" (EOEA 2004). The Action Plan also explains that "concerns have been raised that the rapid changes in flow caused by hydropeaking create unstable habitats that reduce the abundance and diversity of aquatic macroinvertebrates and fish. However, there is currently a lack of data to properly evaluate these concerns" (EOEA 2004). This study aimed to fill this critical information gap relating to the ecological health of the Deerfield River; the data can serve as a baseline of the status of the benthic community of this valuable resource to the region and its citizens.

The goal of this study was to determine whether differences in macroinvertebrate abundance and community structure occur between regulated sections of the Deerfield River and nearby unregulated river reaches. Specific objectives included:

1) determining whether macroinvertebrates occur in higher abundance in unregulated river reaches than do those in regulated river reaches that regularly experience high water velocities,

2) determining whether macroinvertebrate communities in unregulated river reaches show a higher taxonomic richness (more species) than do those in regulated river reaches,

3) determining whether macroinvertebrate communities in unregulated river reaches exhibit a different functional and structural composition than do those in regulated river reaches.

METHODS

STUDY DESIGN AND SITE SELECTION

Macroinvertebrates were sampled from regulated reaches of the Deerfield River, as well as from unregulated reaches of multiple tributaries to allow comparisons of communities from regulated and unregulated reaches. Four regulated reaches were selected from immediately below Fife Brook Dam downriver to the town of Charlemont (Table 1). Scheduled hydropeaking releases from Fife Brook Dam normally occur nearly daily through the summer months; these releases increase summer flows from 125 cfs baseflow conditions to 700-1,000 cfs. More than one hundred such releases are scheduled annually between April 1 and October 31; many unscheduled releases also occur during this period to accommodate summertime electricity generation demands. A second mainstem sampling reach was established approximately 2.5 miles downriver from Fife Brook dam; this reach was located approximately 150 m upriver of the "Bridge to Nowhere." A third mainstem sampling reach was selected immediately upriver of the confluence with the Cold River at river mile 30, and the fourth mainstem sampling reach was selected downriver of the town of Charlemont at approximately river mile 25. To serve as unregulated control reaches, three tributary rivers to the Deerfield River were also selected for sampling following review of available biological data and consultation with DEP staff. The lower reaches of the North River and the Cold River in Massachusetts and the West Branch of the Deerfield River in Vermont, were each sampled, as it was deemed that each of these would serve as suitable unregulated control reaches against which to compare biological conditions in the regulated reaches of the Deerfield River.

Table 1. Sampling design showing the number of sample sites, seasons, and macroinvertebrate samples collected. RM (river mile) = miles upriver of confluence with the Connecticut River.

	Season		
Reach	**Summer**	**Fall**	**Total**
Regulated – Hydropeaking			
1 Deerfield River below Fife Brook Dam (RM 37)	3	3	6
2 Deerfield River above Bridge to Nowhere (RM 34.5)	3	3	6
3 Deerfield River above Cold River confluence (RM 30)	3	3	6
4 Deerfield River below Charlemont (RM 25)	3	3	6
Reference – No Hydropeaking			
1 North River (confluence at RM 19.5)	3	3	6
2 Cold River (confluence at RM 30)	3	3	6
3 West Branch Deerfield River	3	3	6
Total	21	21	42

SAMPLE AND DATA COLLECTION

Macroinvertebrate communities were sampled between July 26 and 29, and again between September 27 and 29, 2006 from each reach. Three replicate samples were collected from each reach during each sampling period to quantify within-reach variability. Macroinvertebrate samples were collected using standard methods employed by the MA DEP for assessing the condition of macroinvertebrate communities in Massachusetts streams (Nuzzo 2003). These methods are based on the US EPA Rapid Bioassessment Protocols (RBPs) for wadeable streams and rivers (Barbour et al. 1999). Macroinvertebrates were collected from each site using kick-sampling, a method by which organisms are sampled by disturbing streambed substrates and catching dislodged organisms in a net. Three replicate samples, each consisting of ten benthic kick samples of approximately 0.46 m x 0.46 m were collected. Samples were labeled and preserved in the field with 95% denatured Ethanol for later processing and identification in the laboratory. Macroinvertebrates were sampled from wadeable riffle habitat (0.75 to 2.0

feet deep in each river reach) during low-flow conditions (i.e. when water releases are not occurring). Water depth, velocity, and substrate composition were measured at each kick-net sampling location. Water velocity measurements were recorded from the center of each 0.46 X 0.46 m area sampled using a Marsh-McBirney FlowMate Model 2000 flowmeter.

Physical data were also collected from each sampling reach. Substrate composition of each sample reach was measured using Wolman pebble counts (Wolman 1954). Onset Water Temp Pro temperature loggers set to record water temperatures every 15 minutes were deployed according to DWM standard operating procedures (DWM 2005) in each reach during the first sampling episode and retrieved during the September sampling episode.

MACROINVERTEBRATE SAMPLE PROCESSING

Macroinvertebrate samples were sorted to remove a 300-organism subsample from the original sample using a Caton gridded tray. Specimens were identified to the lowest practical taxonomic level (generally genus or species and following the same level of resolution used for the 2005 MA DEP bioassessment of the Deerfield River watershed) as allowed by specimen condition and maturity. Chironomidae were left at the family level owing to the large numbers of very small, immature larvae in the samples. Taxonomic keys used included Merritt and Cummins 1996, Wiggins 1996, Stewart and Stark 2002, Peckarsky et al. 1990, and Pennak 1989).

DATA ANALYSIS

Raw taxonomic and count data were entered into an Excel spreadsheet and cross checked for errors and omissions against laboratory bench sheets before analysis. Data were then summarized using a number of community attribute data both used by DEP/DWM to assess Massachusetts surface waters for biological integrity and a number of additional metrics known to be potentially responsive to hydropeaking perturbations. Data were analyzed with a combination of graphic and statistical analyses of community composition and attribute data. Two-way analysis of variance was used to detect treatment effects on selected community attributes and overall abundance as response variables. Test results were considered significant when $p<0.05$.

Multivariate analyses were performed in PC-Ord Version 4 statistical software. Macroinvertebrate density data were log-transformed (using log10 [x+1]) to reduce the influence of numerically-dominant taxa (Krebs, 1989). This type of transformation is useful when there is a high degree of variation in the number of organisms represented by different taxa (McCune & Mefford, 1999) and has routinely been used on macroinvertebrate community data prior to performing multivariate analysis (e.g., Jackson, 1993; Reece & Richardson, 2000; Rempel, Richardson & Healey, 2000; Zimmer, Hansen & Butler, 2000; Cole et al., 2003). Non-metric multidimensional scaling (NMS) was performed using the Sorenson (Bray-Curtis) distance measure and a minimum of 400 iterations. NMS, a non-parametric ordination technique, was used because it assumes no underlying distribution of the data, is robust to data departures from normality, and therefore is suggested for use with ecological data (McCune & Mefford, 1999).

QUALITY ASSURANCE/QUALITY CONTROL

In order to ensure data quality and render the data more useful for watershed assessment and planning purposes, a QAPP was prepared and submitted to DEP for approval prior to the commencement of any project activities. Quality control procedures included thorough training and supervision of any volunteers participating in field data and sample collection, assembling a voucher collection of taxa identified for the project, and maintaining macroinvertebrate samples for a period of no less than five years following completion of the project. A subset of the samples was re-identified by a second taxonomist as further quality control.

RESULTS

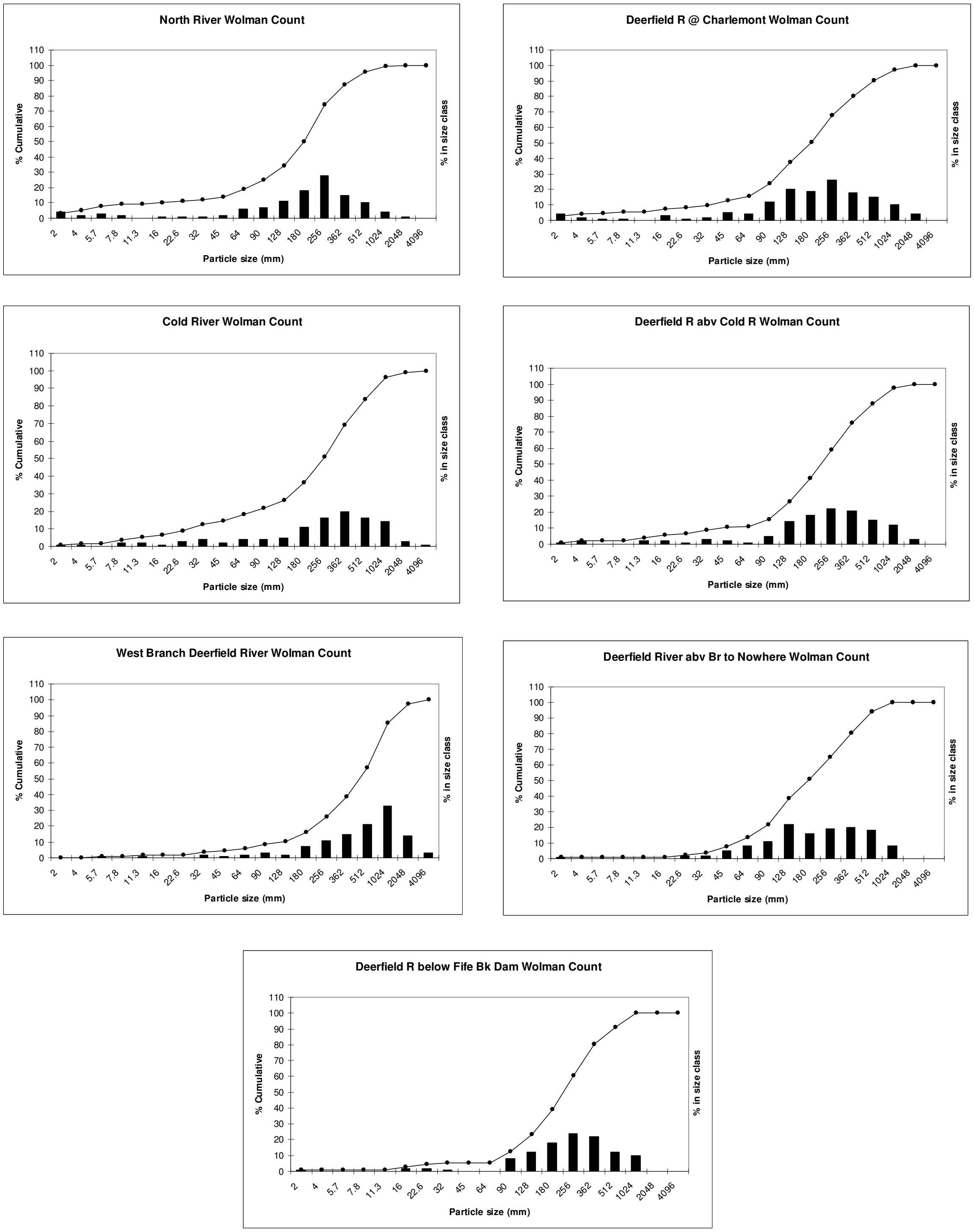
ENVIRONMENTAL CONDITIONS

CHANNEL DIMENSIONS AND GENERAL CHARACTER

All sample reaches included prevalent riffle habitat and coarse substrates conducive to macroinvertebrate colonization. Channel dimensions were smallest in the West Branch Deerfield River and Cold River, with bankfull widths measuring 18 and 23 meters, respectively. Bankfull width of the North River sample reach was 32 m. Mainstem Deerfield River sample reach bankfull widths ranged from 43 m in the below-Fife reach to 69 m in the Charlemont reach. Bankfull widths in the above-bridge-to-Nowhere and above-Cold-River reaches were 49 and 46 m, respectively. Although not measured directly, by observation channel gradient was steepest in the West Branch of the Deerfield River, and secondarily so on the Cold River. Among the tributaries, the North River gradient was lowest, most closely resembling that of the mainstem Deerfield River. Channel gradient variation across the mainstem sites was too subtle to distinguish among the reaches through visual observation. Five of the seven reaches supported forested riparian zones along both banks. Route 100 closely encroaches on the north bank of the West Branch of the Deerfield River, thereby preventing any significant canopy development along this reach. Likewise, Route 2 abuts the lower Deerfield River sample reach's north bank.

SUBSTRATE COMPOSITION

Wolman Pebble count data suggest that substrate conditions in the Cold and North Rivers were similar to those in the mainstem Deerfield River reaches, as the median particle size class (D50) was 180 cm and 256 cm in the North and Cold rivers, respectively, while the median particle size class was either 180 cm or 256 cm in each of the four mainstem reaches (Figure 1, Table 2). Substrate particles tended to be larger in the West Branch of the Deerfield River reach with a median particle size class of 512 cm,



North River Wolman Count

Deerfield R @ Charlemont Wolman Count

Cold River Wolman Count

Deerfield R abv Cold R Wolman Count

West Branch Deerfield River Wolman Count

Deerfield River abv Br to Nowhere Wolman Count

Deerfield R below Fife Bk Dam Wolman Count

Figure 1. Substrate size frequency graphs derived from Wolman Pebble counts conducted in seven river reaches in the Deerfield River watershed, Massachusetts.

as evidenced by the right-ward shift in the graph (Figure 1). The percent of fine substrate particles varied among reaches, with the highest quantities occurring in the North River and lowest Deerfield River reach (Table 2) and the lowest occurring in the West Branch of the Deerfield River.

TEMPERATURE REGIME

Temperature loggers were retrieved from six of the seven reaches and data were successfully downloaded from five of those retrieved. Consequently, no temperature data are available for the Deerfield River reaches below Charlemont and above the Bridge to Nowhere. The average daily mean water temperature in August was similar between the above-Cold-River (18.7^{o}C) and below-Fife (18.5^{o}C) Deerfield River reaches and the West Branch (18.3^{o}C) and Cold River (18.2^{o}C). The average daily mean temperature of the North River was warmest at 20.3^{o}C. Daily average maximum temperatures in August were lowest in the below-Fife Deerfield River reach (18.8 C) relative to all other four reaches from which temperature data were retrieved (range 19.7 to 22.2^{o}C). Daily average minimum temperatures in August were highest in the North River (18.4^{o}C) and below Fife Deerfield River (18.2C^{o}) reaches (Table 2). Average diel change in water temperature was lowest in the below-Fife Deerfield River reach at 0.7^{o}C, considerably smaller than any of the other daily average changes, which ranged from 2.8 to 4.7^{o}C (Table 2).

Table 2. Environmental conditions measured in summer 2006 from seven river reaches in the Deerfield River watershed, Massachusetts.

	Tributaries			Deerfield River			
Variable	North R	West B	Cold R	Charlemont	Abv Cold	Abv Br NoWh	Below Fife
Bankfull Width							
Substrate:							
D50 (mm)	180	512	256	180	256	180	256
Percent Fines	3.4	0	0.9	2.7	0.8	0.8	0.9
Aug. Water Temp:							
Avg Daily Max	22.2	19.7	21.0		21.0		18.8
Avg Daily Min	18.4	16.9	16.3		17.1		18.2
Avg Daily Mean	20.3	18.3	18.2		18.7		18.5
Avg Max-Min	3.8	2.8	4.7		3.9		0.7
Sept. Water Temp:							
Avg Daily Max	17.3	15.3	15.7		18.5		17.5
Avg Daily Min	14.6	13.2	12.6		15.3		16.9
Avg Daily Mean	15.9	14.3	13.9		16.7		17.1
Avg Max-Min	2.7	2.2	3.2		3.2		0.7
Hydropeaking	N	N	N	Y	Y	Y	Y

In September, the average daily mean water temperature was highest in the two Deerfield River reaches (Table 2). The September average daily maximum temperature was highest in the two Deerfield River reaches and in the North River, while the average daily minimum water temperature was higher in the below-Fife Deerfield River reach than in any other reach (Table 2). As in August, the average daily diel change in water temperature was only 0.7°C in the below-Fife Deerfield River reach, while it ranged from 2.2 to 3.2°C in the other four reaches (Table 2).

MICROHABITAT CONDITIONS AT SAMPLE LOCATIONS

Microhabitat conditions at kicknet sample locations were similar among all reaches in both July and September. Average water velocity of sample locations ranged from 1.05 to 1.62 fps in July and 1.10 to 1.62 fps in September (Table 3). Average sample depth ranged from 20.4 cm to 29.2 cm in August and from 18.7 to 26.3 cm in September.

Table 3. Microhabitat conditions measured at kicknet sample locations within seven river reaches sampled for macroinvertebrates in the Deerfield River watershed, Massachusetts, in July and September, 2006.

	July Sampling				September Sampling			
Site	Avg Veloc (fps)	SD	Avg Depth (cm)	SD	Avg Veloc (fps)	SD	Avg Depth (cm)	SD
Cold River	1.41	0.40	24.7	3.7	1.25	0.46	18.7	3.7
DR abv Cold	1.49	0.47	26.2	6.5	1.42	0.36	26.3	4.5
DR abv Br to NoWh	1.62	0.38	27.3	3.3	1.62	0.41	22.5	2.7
DR below Fife	1.57	0.34	29.2	5.3	1.37	0.38	21.9	3.9
DR Old Willow	1.54	0.42	24.6	4.7	1.36	0.32	23.1	3.3
North River	1.29	0.47	20.4	3.3	1.26	0.50	20.9	4.4
West Branch	1.05	0.59	23.1	7.3	1.10	0.32	20.9	4.2

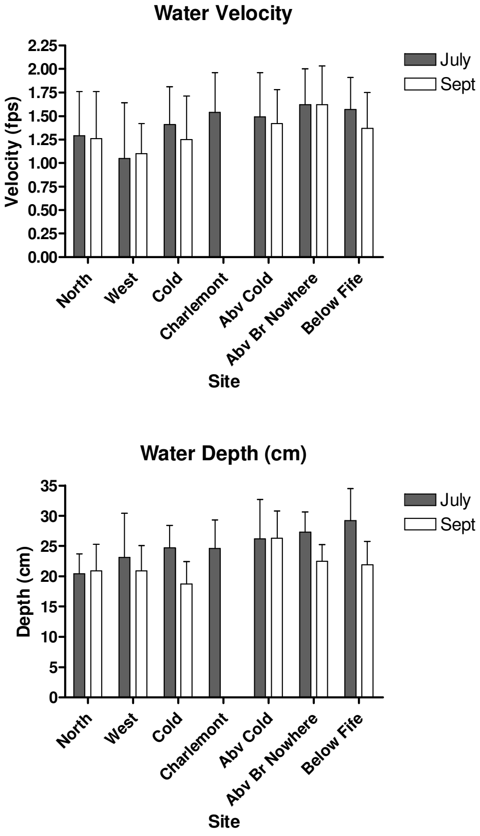


Figure 2. Average (+SD) microhabitat conditions measured at kicknet sample locations within seven river reaches sampled for macroinvertebrates in the Deerfield River watershed, Massachusetts, in July and September, 2006.

MACROINVERTEBRATE COMMUNITIES

ORDINATION RESULTS

NMS ordination of both July and September macroinvertebrate community data show a general pattern of grouping of tributary sites and a gradient in community composition in mainstem sites that suggest that taxonomic composition of the below-Fife and above-Bridge-to-Nowhere sites are most dissimilar and the lower Deerfield River site below Charlemont is most similar to the tributary reaches (Figure 3).

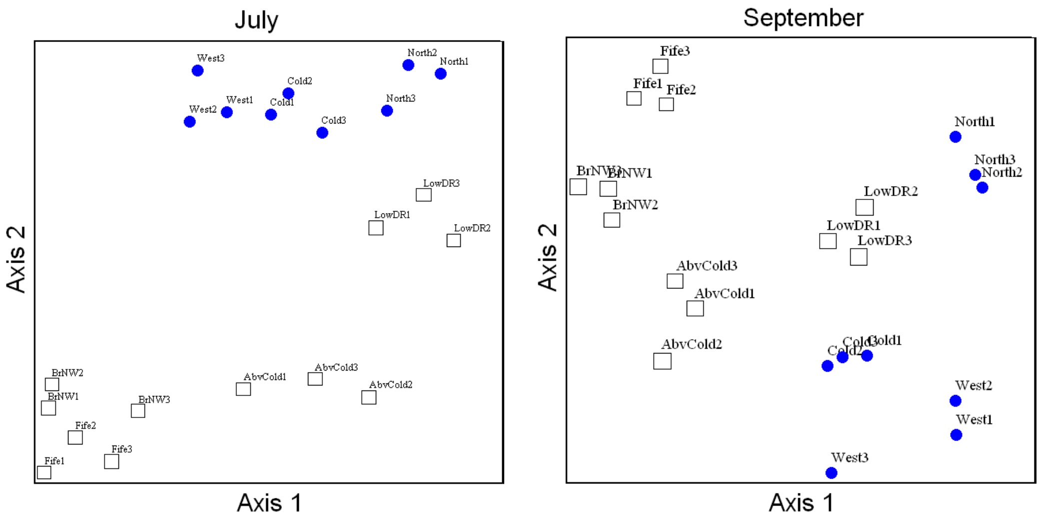


Figure 3. NMS ordination bi-plots of macroinvertebrate communities sampled from seven river reaches in the Deerfield River watershed, Massachusetts, in July and September, 2006. Tributary site replicate samples are solid circles; mainstem site replicate samples are open squares.

TAXONOMIC COMPOSITION

Chironomidae were the dominant taxon in six of seven reaches in late July (Table 4). Mayflies (Ephemeroptera) were also abundant in most reaches at this time, but were relatively low in abundance in the two upper Deerfield River reaches. Where mayflies were abundant, the most common taxa were those of the Baetidae family, including *Acentrella turbida*, *Plauditus* species, and several *Baetis* species. Caddisflies were abundant in July in several of the mainstem Deerfield River reaches, owing largely to an abundance of filter-feeding Hydropsychidae caddisflies in the Charlemont, above-Bridge-to-Nowhere, and below-Fife reaches.

By late September, Chironomidae were less dominant in the tributary reaches as their numbers remained similar to those in July, yet mayfly and/or caddisfly abundance increased. A dramatic increase in caddisfly abundance occurred in the North River, with numbers increasing from 370 per m^2 in July to 2,496 per m^2 in September. The filter-feeding caddisflies, *Cheumatopsyche* and *Hydropsyche*, were responsible for this significant increase in caddisfly abundance. Chironomidae abundance increased from July to September in most of the Deerfield River reaches, remaining similar only in the below-Fife reach. Tributary reaches were generally co-dominated by Chironomidae, mayflies, and caddisflies in September (Table 4). The two lower Deerfield River reaches exhibited a similar community composition, but Oligochaetes were much more abundant than in tributary reaches. The two uppermost Deerfield River reaches showed the largest divergence in community composition from the tributary reaches, as filter-feeding freshwater clams were abundant in both reaches (Table 4), while mayfly abundance remained low compared to tributary reaches. Stonefly abundance was also relatively low in the uppermost reaches in September, particularly in the below-Fife reach, as compared to stonefly abundance in the tributary reaches (Table 4).

Table 4. Taxonomic composition and abundance (number of individuals per m^2) of macroinvertebrate communities sampled from seven river reaches in the Deerfield River watershed, Massachusetts, in July and September, 2006

	Tributaries			Deerfield River			
Taxonomic Group	North R	West Br	Cold R	Charlemont	abv Cold River	Abv Br to Nowh	below Fife
				JULY			
Oligochaeta	92	20	106	409	726	171	82
Chironomidae	661	3024	2246	2026	2913	3042	1767
Other Diptera	165	46	120	93	50	93	27
Freshwater Clams	0	0	0	0	79	149	483
Coleoptera	140	52	57	79	274	207	22
Ephemeroptera	1707	992	1434	1615	640	163	66
Plecoptera	58	212	127	52	50	37	106
Trichoptera	370	211	461	996	205	664	745
Other Taxa	159	42	149	110	356	196	125
				SEPTEMBER			
Oligochaeta	136	86	268	1153	1144	519	49
Chironomidae	537	3078	1354	3140	5624	9893	1527
Other Diptera	201	43	76	76	43	191	49
Freshwater Clams	0	0	0	0	41	509	1937
Coleoptera	174	78	44	94	203	93	25
Ephemeroptera	1028	1704	1603	979	880	447	282
Plecoptera	84	555	284	117	89	<10	24
Trichoptera	2496	417	1048	1741	664	1852	1695
Other Taxa	198	58	125	175	221	624	135

A number of taxa that were found in all of the tributary reaches and the lower Deerfield River reaches were not collected from one or both of the upper Deerfield River reaches (Table 5). Three otherwise common and ubiquitous Baetidae mayflies were not found in the below-Fife and Above-Bridge-to-Nowhere reaches in September. Similarly, the heptageniid mayfly, *Epeorus vitreus*, was sampled from every other reach but these two in both July and September.

Three stonefly taxa that occurred in all tributary reaches also were not found in one or more of the upper Deerfield River reaches. The predaceous perlid stonefly, *Agnetina capitata*, was not sampled from the below-Fife reach in July or September. Another predacious perlid stonefly, *Paragnetina immarginata*, was also absent from samples from the two upper reaches in July and September, despite occurring in all other reaches. Likewise, the large perlodid stonefly, *Isogenoides*, was absent from samples collected from the three uppermost Deerfield River reaches (Table 5).

Conversely, the only taxa that occurred in the mainstem that were not sampled from the tributary reaches were a single crayfish specimen, a single Isopoda specimen of the genus *Caecidotea*, and a single immature *Ephemera* mayfly specimen.

Table 5. List of taxa that were collected in 2006 from all Deerfield River hydropeaking effects study reaches other than the upper Deerfield River reaches in closest proximity to the Fife Brook dam.

Order/Taxon	Study Period	Not Collected	Collected
Ephemeroptera (Mayfly)			
*Acentrella turbida**	September	Below Fife and Abv Br to Nowhere	All other reaches
Baetis flavistriga	September	Below Fife and Abv Br to Nowhere	All other reaches
*Baetis intercalaris**	September	Below Fife and Abv Br to Nowhere	All other reaches
Epeorus vitreus	July and September	Below Fife and Abv Br to Nowhere	All other reaches
Plecoptera (Stonefly)			
Agnetina capitata	July	Below Fife, Abv Br to Nowhere, and Abv Cold	All other reaches
	September	Below Fife	All other reaches
Paragnetina immarginata	July and September	Below Fife and Abv Br to Nowhere	All other reaches
Isogenoides sp.	September	Below Fife, Abv Br to Nowhere, and Abv Cold	All other reaches

*Also not sampled from the above-Cold-River reach in July

ANOVA ANALYSIS OF SELECTED COMMUNITY ATTRIBUTES

Two-way analysis-of-variance results indicated that four of six community attributes examined were significantly different between tributary and mainstem reaches (Table 6). Total taxonomic richness, EPT richness, mayfly densities, and percent scrapers were all significantly lower in the mainstem reaches than in the tributary reaches.

Table 6. Results of two-way analysis of variance tests performed on macroinvertebrate community attribute data collected from seven river reaches in the Deerfield River watershed, Massachusetts, in July and September, 2006. Treatments were hydro-modified river reaches in the Deerfield River and unregulated control reaches in Deerfield River tributaries. Results in bold are statistically significant ($p<0.05$).

	p-values		
Attribute	Treatment Effect	Sampling Period Effect	Interaction
Total Richness	**0.011**	0.109	0.303
EPT Richness	**0.004**	0.033	0.353
Mayfly Abundance	**0.014**	0.863	0.939
Overall Density	0.085	**0.040**	0.169
Percent Filterers	0.400	0.207	0.851
Percent Scrapers	**<0.001**	**0.047**	**0.010**

Total taxonomic richness was highest in the North River in both July and September (Figure 4). In July, total richness was similar among all of the mainstem reaches and the West Branch control reach. However, September results suggest that richness was generally lower in the mainstem than in the control reaches and decreased with proximity to the Fife Brook dam. EPT richness showed a similar September pattern of decreasing richness with proximity to the dam, and lower richness in the mainstem than in the tributary reaches.

Mayfly abundance was significantly lower in mainstem reaches than in the tributaries (Table 6). This difference is clearly attributable to the low mayfly densities measured in the upper Deerfield River reaches in both July and September. In July, mayfly densities were 163 and 66 individuals per square meter in the above-Bridge-to-Nowhere and below-Fife reaches, respectively. In contrast, mayfly densities averaged 1,378 individuals per square meter in tributaries. July mayfly densities from the downriver mainstem reaches, particularly below Charlemont, were comparable to those in the tributaries (Figure 4). September mayfly densities in the two upper Deerfield River reaches, although higher than in July, were still lowest among the seven reaches (Figure 4).

Although overall macroinvertebrate densities did not differ between mainstem and tributary reaches (Table 6), mainstem overall macroinvertebrate densities in July appeared to decrease with proximity to the Fife Brook Dam (Figure 4). By September, this pattern was almost reversed with densities increasing from Charlemont upriver to the Bridge-to-Nowhere reach, but were then substantially lower (and similar to densities in the tributaries) from the below-Fife reach (Figure 4).

Analysis of filtering and scraper functional feeding guilds indicated that scrapers were less abundant in mainstem reaches than in tributary reaches (Table 6). Scrapers were far less abundant in the below-Fife reach in July than in any other reach (Figure 4), but by September, relative abundance of scrapers had decreased in the other mainstem reaches to an extent that resulted in a large difference in this attribute between tributaries and mainstem reaches (Figure 4). Although filterer relative abundance did not differ between tributary and mainstem reaches, the below-Fife site supported the largest relative abundance of filter-feeding organisms in both July and September. This reach supported larger numbers of filterers than either any tributary reach or any other mainstem reach in July and September (Figure 4).

QUALITY CONTROL RESULTS

Macroinvertebrate samples were processed by a trained technician. The sorted residues of twenty seven samples were inspected by the project manager to ensure that at least 95% percent of all macroinvertebrates were being removed from the subsampled portion. All 27 samples passed these inspections. Two samples were sent to an independent NABS-certified taxonomist for quality control inspection of the taxonomic work performed for this project. Percent agreement between the project taxonomist and the independent QC taxonomist was 95.5%. Additionally, a voucher collection of taxa identified for this project was assembled by the project taxonomist and will be permanently archived by the Deerfield River Watershed Association.

Water temperature data collected with the Water Temp Pro loggers were checked at the beginning and end of each field deployment with in situ readings using a pair of hand-held thermometers. Water temp pro readings were consistently within 0.5^{o}C of the average of the two hand-held thermometer readings.

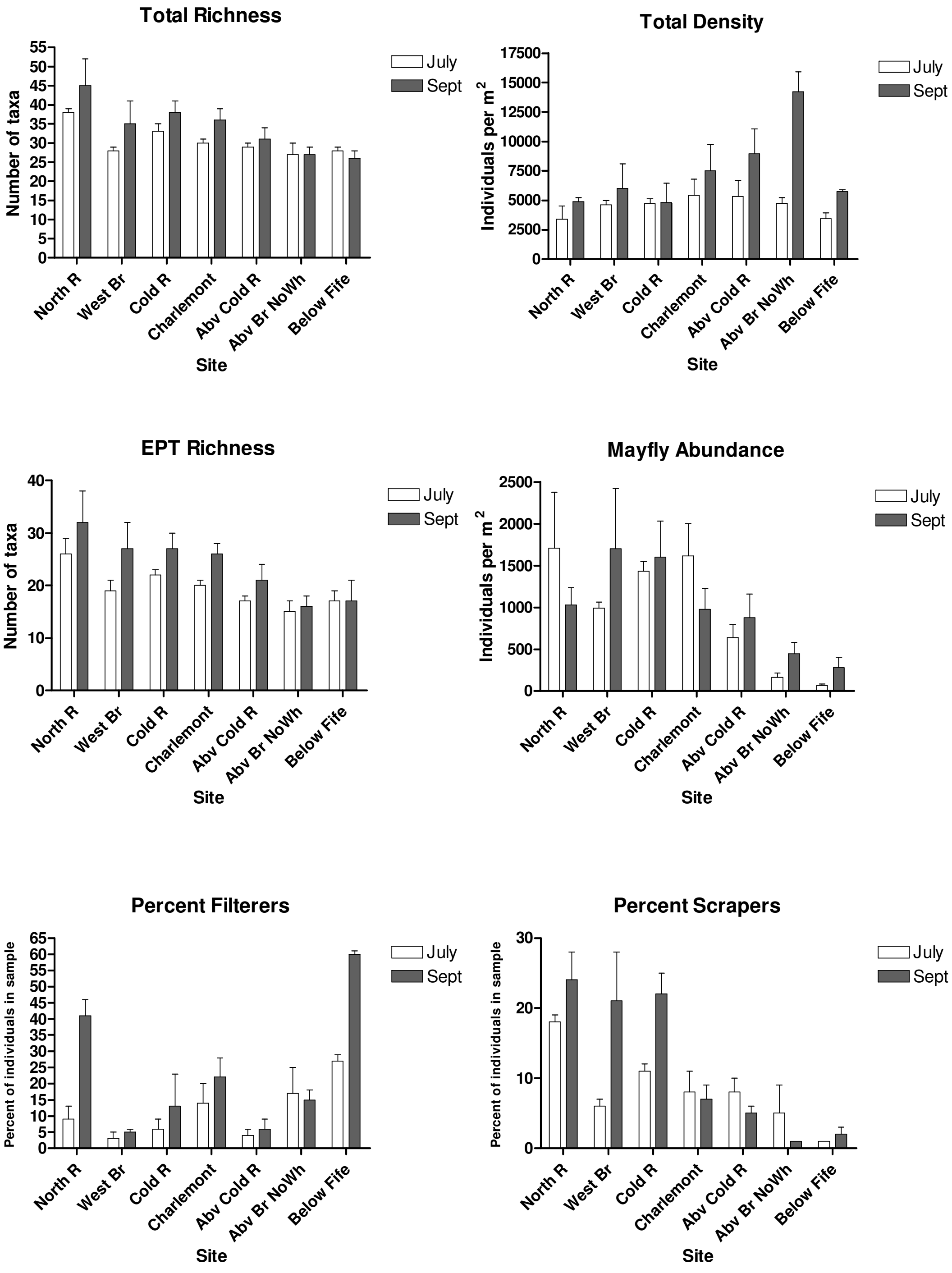


Figure 4. Macroinvertebrate community attributes from seven river reaches in the Deerfield River watershed, Massachusetts, in July and September, 2006.

DISCUSSION

The results of this work indicate that Macroinvertebrate communities of the Deerfield River between Charlemont and the Fife Brook Dam, in relation to communities of unmodified Deerfield River tributaries, show an increasing divergence in community composition with closer proximity to the Fife Brook Dam. Community conditions immediately below Fife Brook dam, characterized by dominance by filter-feeding organisms and Chironomidae, and low abundance of mayflies and stoneflies, differed most from the tributary reaches. These results are similar to those of other studies of reservoir tailwater benthic communities (e.g. Novotny 1985) that have found the most common taxa in these areas to include Chironomidae and filter-feeding organisms such as Hydropsychidae caddisflies. Filter-feeding freshwater clams, absent or rare in other reaches, were also very abundant in the below-Fife reach. This dominance by filter-feeding organisms immediately below the tailwater release point suggests that organisms of this functional group are responding to an increase in filterable food quantities in the water being carried out of the reservoir, likely reservoir plankton, which would be expected to peak in concentrations in early fall, when filter-feeder densities were highest during this study. A decrease in filter-feeding organisms in the following two downriver reaches and then an increase in the reach below Charlemont suggest that less filterable food is available to organisms in the lower reaches above Charlemont, but primary production within the river or other inputs of fine organic material may be resulting in an increase in filterable food and filter-feeding organisms as far downriver as below Charlemont. The below-Charlemont reach occurred downriver of both agricultural activity and the Charlemont waste water treatment plant, each of which potentially contribute organic material to this section of the Deerfield River.

Mayflies were low in abundance in the upper Deerfield River reaches in both July and September. These results are also consistent with those of other tailwater benthic community studies that have found mayflies to be low in abundance immediately below dams, but increase in abundance with downriver distance from this point (Cereghino and Lavandier 1998, Novotny 1985). These other studies have suggested several potential causes for the observed patterns, including altered thermal regimes that interfere with life stage development and altered flow regimes that may result in both accidental displacement and behavioral drift. Either mechanism is a plausible explanation for these patterns observed in the Deerfield River.

The absence of a number of mayfly and stonefly taxa from either the below-Fife reach or both of the upper Deerfield River reaches suggests that either thermal or hydrological modification of the upper reaches is precluding some taxa from occurring in the upper reaches in the same numbers that they occur elsewhere in less affected reaches. Temperature data collected during this study suggest that both diel and seasonal temperature regimes are altered by the Fife Brook reservoir and that these effects are ameliorated further downriver. Generally, August daily mean water temperatures were similar between the mainstem and tributary reaches, but September daily mean temperatures were warmer in the mainstem than in the tributaries, suggesting a delaying effect of the reservoir on the seasonal thermal regime in the river immediately below. Although the tributaries, as smaller water bodies, would be expected to cool more rapidly with cooler air temperatures, the effect of the reservoir on delaying cooling of the river was evident in both the August and September data, as the average diel change in water temperature was only 0.7°C in each month, versus changes of 2.2 to nearly 5 °C in all of the other reaches, including the above-Cold-River reach on the Deerfield River. Collectively, the temperature data suggest that the thermal regime below Fife Brook dam may be altered to the extent that spring water temperatures could be insufficient to allow normal development of some aquatic insects. Just as the river immediately below Fife Brook dam cools more slowly in the fall, it would be expected to warm more slowly in the spring. Because temperature is a known major factor affecting the seasonality and development of mayflies (Newbold, Sweeney, and Vannote 1994), it follows that the reduced richness and abundance of mayflies in the upper Deerfield River below Fife Brook dam may potentially be affected by an altered thermal regime. A more thorough study could examine community composition and insect larval development rates in relation to the river's thermal regime to address this issue, but until such work is performed, the mechanisms producing the observed patterns remain uncertain.

Others have suggested that the reduction of numbers of large predators (such as large stoneflies) below dams may contribute to the establishment of large numbers of small organisms such as Chironomidae (Novotny 1985). Such dynamics may be occurring in the Deerfield River, as the lower numbers of predaceous stoneflies in the upper reaches may be allowing large numbers of Chironomidae to become established, particularly in areas of the river in the above-Bridge-to-Nowhere vicinity, where Chironomidae were far more abundant than in any other reach in September, and stonefly abundance was reduced.

Although macroinvertebrate communities in Deerfield River reaches in closer proximity to the Fife Brook dam appear to be affected by the altered environment created by the dam, mainstem reaches further downriver supported macroinvertebrate communities that were generally comparable to those observed in tributaries. EPT (mayfly, stonefly, and caddisfly) richness was highest below Charlemont among all Deerfield River reaches in each season and mayfly abundance was the second highest measured among all seven reaches in September. Although no temperature data were collected from this reach, the thermal regime is likely similar to that of the North River with wide diel fluctuations and a relatively normal seasonal regime. Also, although hydropeaking flows pass through this reach as frequently as they do through the upper reaches (the river is free flowing between all four of the mainstem reaches included in this study), the effects on the benthic community in this reach may be less significant because the channel is considerably larger and therefore better able to accommodate the increased discharge and because the rate that the discharge increases due to hydropeaking is considerably slower than it is immediately below the dam (based on personal observation). This last point is a particularly germane discussion point, as it is thought that the ability of certain aquatic insects to respond to rising water levels is related to the rate of increase of river stage and discharge. As such, slower ramping rates and a less pronounced effect of the peaking flows on river hydraulics owing to increased channel dimensions, may serve to sufficiently ameliorate the potentially deleterious effects of hydropeaking flows on the benthic community in these downriver reaches.

The effects of Fife Brook dam and hydropeaking activities on macroinvertebrate communities inhabiting riffle habitat of the Deerfield River appear to be spatially limited. Differences in macroinvertebrate communities that appear to be related to proximity to Fife Brook dam were most pronounced immediately below the dam and at the above-

Bridge-to-Nowhere reach located approximately 2.5 miles below Fife Brook dam. Metric analysis and multivariate analysis both suggested that community conditions were more similar to tributary conditions approximately seven miles below the Fife Brook dam, where the seasonal thermal regime was also more similar to that observed in the tributaries. Twelve miles below Fife Brook dam at the Charlemont sampling reach, macroinvertebrate community composition more closely resembled that of the tributaries than the uppermost mainstem reaches, suggesting that whatever conditions are modifying communities upriver are abated in these lower reaches between Charlemont and the #4 dam.

The patterns observed in this study, although spatially related to proximity to the Fife Brook dam, can not be said to be directly related to the current hydropeaking regime. Altered water temperatures, nutrient content, and food resources in the river below Fife Brook dam also potentially contribute to these observed patterns. Separating out the relative contribution of these potentially causative factors is beyond the scope of this study. These data should serve as a baseline for understanding conditions under the current river management regime. Continued monitoring of the benthic communities should help even better characterize these conditions in relation to the current range of environmental conditions created by the hydropeaking operations and can help quantify changes to the biology that may result from future modification of the hydropeaking activities.

Because previous work has demonstrated that the abundance and distribution patterns of some aquatic insects in rivers is affected by current velocities and water depth (Needham and Usinger 1956, Minshall and Minshall 1977), an effort was made in this study to minimize these effects across replicate samples and among reaches by selecting relatively uniform microhabitat characteristics with respect to these features. Because a relatively narrow range of microhabitat types was sampled, it is plausible that insects occupying other habitat types and even other microhabitats within riffles (e.g., extremely shallow or deep portions of riffles, or areas with very fast or slow current velocities) may be responding differently to these environmental alterations. It is important to note that macroinvertebrate communities in other habitats within the Deerfield River may be differentially affected by the types of perturbations resulting from hydropeaking activities from an upriver impoundment. This investigation included no assessment of communities from pools or other slow-water habitats. At least one study has shown significant decreases in the abundance and diversity of aquatic insects inhabiting pools in a river undergoing regular hydropeaking activity (Trotzsky and Gregory 1974).

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