The realization of a pipe dream: effective partnerships in community-based urban stream restoration

A case study of the Mully Grub, Letort Spring Run, Cumberland County, PA

Candie C. Wilderman
Environmental Studies Department
Dickinson College
June, 2004

LIST OF STUDENT PARTICIPANTS IN THE MULLY GRUB RESEARCH PROJECT

Fall, 1998

Blacknall, Andre
Eppensteiner, Jocelyn
Giunta, Kirsten
Justin, Gold
Leary, David
Long, Nicole
Magaro, Kristy
Pickering, Rachel
Pragroff, David
Schinnerer, Jeffrey
Schoppe, Alexis
Trethewey, Amy
Verni, Christopher
Vorhees, Karen
Wallinger. Eric
Walker, Gregory
Wetzler, Karen
Whitehead, Caroline

Fall, 1999

Briddell, Christiana
Cohen, Jonathan
Cowart, Adele
Donahue, Joseph
Gibbons, Melissa
Glenn, Rebecca
Hill, Janice
Hoffner, Gregory
Johnson, Evan
Keidel, Christian
Kenney, Michelle
Mackey, Christine
Martin, Megan
McGill, Jared
Mondino, Gabriel
Runge, Jeffrey
Sergeant, Kara
Shannon, Melissa
Vezina, Amy
Yoachim, Ann
Zubowicz, Lisa

LIST OF ALLARM STUDENT STAFF WHO PARTICIPATED IN THE MULLY GRUB PROJECT

Allio, Maggie
Berns, Rob
Blum, Danny
Briddell, Christiana
Cowher, Pamela
Dean, Melanie
Enderlin, Peter
Foster, Claire
Friedmann, Heather
Froggatt, Claire
Funk, Emily
Haney, Colleen
Hoffman, Katie
Johnston, Jackie
Junium, Chris
Karasack, Becky
Lewis, Vallie
Pohlman, Brent
Pye, Stephanie
Schoppe, Alexis
Schwerin, Andrew
Sergeant, Kara
Spencer, Jessica
Still, Allison
Sutton, Patrick
Vastine, Julie
Vecchione, Nicole
Verni, Chris
Vezina, Amy
Vorhees, Karen
Walker, Becky
Walters, Laura
Weintraub, Micah

ACKNOWLEDGEMENTS

In addition to the students listed after the title page and the organizations listed in Figure 26, the author wishes to acknowledge the following people and organizations for their contribution to this project: Lauren Imgrund, Director of ALLARM, for her leadership role in the implementation and ongoing assessment of the entire project; Alissa Barron, former Assistant Director of ALLARM and Julie Vastine, current Assistant Director of ALLARM, for providing supervision and inspiration for ALLARM student staff, whose imaginations, dreams, and hard work have driven the implementation of the project; Brian Fischbach, Executive Director of the Letort Regional Authority, for his support and involvement throughout the project; James Bartoli, who so generously allowed us to construct a wetland on his property and who supported our efforts throughout the project; Robert Schott, PA Department of Environmental Protection, for his technical advice and for arranging for the Department to perform laboratory analyses on the sediments; Mary Golab and Carl Rohr, PA Department of Environmental Protection, who helped us find support monies and provided us with their expert advice; Mark Kauffman, former Academic Technician for the Geology and Environmental Studies Departments, for his field and laboratory assistance during the student studies; Cathy Sroka, former principal of Letort Elementary School, who opened her school's doors to our students and allowed her teachers and students to be fully involved in the riparian zone project; and finally Cumberland Valley Trout Unlimited, whose members first planted the idea for a study of the Mully Grub in the author's mind.

TABLE OF CONTENTS

PART II. THE MULLY GRUB RESTORATION/ MITIGATION PROJECT

LIST OF FIGURES AND TABLES

EXECUTIVE SUMMARY

The following paper documents a stream restoration/mitigation project within the Letort Spring Run watershed in Cumberland County, PA, that has involved a strong partnership between the Environmental Studies Department at Dickinson College and the community of Carlisle, PA. This project grew out of a concern expressed by the community regarding the impact of stormwater runoff from the town of Carlisle on the ability of the Letort Spring Run to support a native brown trout fishery throughout its extent. Students, under the supervision of Professor Candie C. Wilderman, scientifically documented the impact of urban runoff conveyed through a small tributary, known as the Mully Grub, to the Letort Spring Run. Through a partnership between the Alliance for Aquatic Resource Monitoring (ALLARM) and the Letort Regional Authority (LRA), grant monies were raised to implement the proposed student project. The restoration project, including a constructed wetland and a wooded riparian zone, was carried out by local volunteers, school groups, businesses, local government, and non-governmental organizations.

THE STUDY

Multiple lines of evidence were used to document the impact of urban runoff on the Mully Grub and the Letort Spring Run, including water quality at street and instream sites during and between storm events, sediment quality, macroinvertebrate communities, habitat assessments, diatom communities, meiofaunal communities, and channel stability assessments.

Twenty-one chemical parameters were measured during stormwater events at 6 street sites within the Mully Grub subwatershed. The ranking of sites from most impacted to least impacted falls along a gradient of decreasing impermeable area and decreasing vehicular activity, indicating that the pollutants in the stormwater runoff are closely related to the amount of urbanization in the area surrounding the sampling sites. Average concentrations of major pollutants in the Mully Grub street sites are comparable to concentrations reported in the literature at other residential, suburban areas and slightly lower than more urbanized areas.

A comparison of stormwater events indicates that there is a negative relationship between the amount of rainfall during the week prior to sampling and the pollution level of the runoff. The data also suggest that the amount of snowfall during the previous month is positively correlated with the severity of the pollution event. These data corroborate other studies which have shown the "cleansing effects" of recent rainfall, as well as the high negative impact of snowmelt, on the quality of stormwater runoff.

The same 21 chemical parameters measured in street runoff were also measured at 5 instream sites in the Mully Grub and the Letort Spring Run between and during storm events. During storms, higher concentrations of the pollutants associated with vehicular

activity and organic pollution are found in the Mully Grub. During periods between storm samplings, when most of the water in the Mully Grub is from limestone, groundwater springs beneath the town of Carlisle, the Mully Gub shows higher concentrations of parameters that are typically high in the local groundwater, such as nitrate, conductivity, alkalinity, and hardness. These patterns clearly demonstrate that the Mully Grub is adversely impacted by the pollutants found in urban runoff during storm events, and then returns to a higher water quality typical of our limestone streams and groundwater, during base flow conditions.

Comparing water quality in the Letort Spring Run upstream and downstream from the Mully Grub confluence during urban runoff events demonstrates that the pollutants conveyed to the Mully Grub have an adverse impact on water quality in the Letort Spring Run. These patterns clearly demonstrate that not only are pollutants in urban runoff having an impact on the Mully Grub, but that the Mully Grub is then conveying these pollutants into the Letort Spring Run.

Nine metals and total petroleum hydrocarbons were analyzed in sediments from the 5 instream sites. These data indicate 7 of the 10 analytes show their highest concentrations at the most upstream Mully Grub site, that is, the Hanover St. outfall; the positioning of these high concentrations at the first site below the outfall clearly implicates stormwater runoff as the primary contaminant source. These same 7 analytes show elevated concentrations in the Letort sediments after the confluence of the Mully Grub in comparison to the site upstream from the confluence, demonstrating a clear impact of the Mully Grub as it conveys stormwater runoff to the Letort Spring Run.

The average concentrations of total petroleum hydrocarbons, lead and zinc are considerably higher in the Mully Grub sediments than in any other section of the Letort Spring Run. Lead falls into the heavily polluted category for sediments in the Mully Grub and represents the worst contaminants in the sediments. Both zinc and copper are elevated in the Mully Grub in comparison to other sections of the Letort and fall into the moderately polluted classification for sediments. Zinc concentrations are almost 3x higher in the Mully Grub than other sections of the Letort.

Sediments were also analyzed for pesticides. The number of pesticides found in the sediment samples from the Mully Grub are comparable to the numbers found at the other major urban outfalls on the Letort Spring Run, with the numbers of compounds decreasing within the Mully Grub with distance downstream. Along the Mully Grub, for any pesticides that show up in the sediment samples at more than one site (gamma-Chlordane, endrin, and 4,4'DDT), the highest concentrations are found in the most upstream site. For every compound for which there is a sediment quality guideline, most of the samples in the Mully Grub exceed that guideline. These data demonstrate clearly that the source of the pesticides is the stormwater runoff and that the Mully Grub is comparable in delivery of pesticides to the other major urban outfalls downstream in the Letort.

The impact of stormwater runoff on water and sediment quality is corroborated by measuring biological community responses. Macroinvertebrate communities in the Mully Grub are dominated by pollution-tolerant macroinvertebrate taxa, such as sewage worms (Tubificidae), bloodworms (Chironomidae), and some molluscs. Absent from or scarce from these communities are the more typical limestone stream taxa such as sowbugs (Ascellidae), scuds (Gammaridae), and mayfly larvae. These communities, when compared to the upstream Letort Spring Run site, show definite impairment; macroinvertebrate communities in the Letort Spring Run just downstream from the Mully Grub confluence show similar impairment. In fact, total scores derived by using the EPA Rapid Bioassessment Protocol II indicate that the Mully Grub sites are the most impacted of any sites studied along the entire Letort Spring Run. An evaluation of instream habitat resulted in classifying all sites as "poor."

All of the dominant diatom genera collected from artificial substrates at 5 sites within the study area are tolerant of high nutrient and turbidity conditions. Diversity is rather low with one or two genera dominating the communities at each site.

The Pielou diversity indices calculated for meiofaunal communities show a greater community diversity in the Letort sites than in the Mully Grub sites. There is not a definite degradation in the Letort meiofaunal community after the confluence with the Mully Grub and so the Mully Grub's influence on the meiofaunal community composition in the Letort is unclear. Using nematode/harpacticoid copepod ratios, our data suggest that organic pollution in the Mully Grub is influencing the meiobenthic community by supporting high nematode populations. It is also possible that poor habitat is negatively influencing harpacticoid copepod populations.

An evaluation of channel stability indicates that all sites rate either poor or fair in regard to such characteristics as bank slope gradient, mass wasting, vegetative bank protection, lower bank rock content, cutting of lower banks, deposition, particle packing, percentage of stable materials, scouring and deposition, and clinging aquatic vegetation. This kind of channel instability is a common outcome of flashy urban flows on stream channel morphology.

All lines of evidence studied indicate that the Mully Grub is being impacted chemically, physically, and biologically by urban runoff, and is delivering this impact to the Letort Spring Run, when it enters that body of water.

THE RESTORATION/MITIGATION PROJECT

Since the Mully Grub is the first major urban outfall into the Letort Spring Run and since it is located next to a school, an urban park, and public baseball fields, students decided to use the results of this study to design and then justify the funding of a restoration/mitigation project. The goals that the students established are as follows: 1) to improve the water quality and habitat in the Mully Grub so that it no longer impacts the Letort Spring Run, 2) to improve the water quality and habitat in the Mully Grub so that ecosystem functionality is increased, 3) to increase the visual appeal of the site, in order to increase the community's sense of caring, pride, and motivation to maintain the project, 4) to involve the community in the project to minimize the cost, to promote educational awareness, to insure long-term maintenance, assessment, and care, to build a sense of stewardship and ownership of the property, and to build community capacity for future projects, 5) to provide an environmental laboratory for the local school for continued environmental education of the children, and 6) to provide a model for other community-based urban restoration/mitigation projects.

Students produced a conceptual design for a restoration/mitigation plan, with the following proposed components: 1) sediment traps installed on storm drains upstream from where the MG emerges from under the ground, 2) a constructed wetland/retention pond, 3) a redesigned and regraded channel and stabilized banks through seeding, mulching, and planting of pre-planted stabilogs, 4) riparian zone restoration, and 5) a wetland meadow along Letort Spring Run.

Two major grants from the Pennsylvania Department of Environmental Protection (DEP), a variety of smaller grants, and in-kind contributions were obtained by ALLARM and LRA to complete most of the components of the students' conceptual plan, and to do additional restoration work on the Letort Spring Run, from 1999-2002. The project was divided into two phases, based on the time frame and the funding source.

Phase I of the restoration project involved implementation of the first three design components of the student plan: 1) the installation of sediment traps in storm drains, 2) channel reconstruction and bank stabilization, and 3) riparian zone restoration.

Four sediment traps (to allow settling of sediments out of the storm water) were installed in storm drains in areas just prior to where the Mully Grub emerges from its journey through the storm drain system in Carlisle, into the channel. The channel was redesigned by the Civil and Environmental Design Group and regraded by the primary contractor, Gleim Environmental Group, resulting in an overall wider channel with more gently sloping banks. The banks themselves were stabilized through seeding, mulching, and the installation of "stabilogs," long, cylindrical bound jute fibers, pre-planted with wetland plants. The planting of the riparian zone was done at the same time as the channel modification activities, and involved participation by all partners. Native trees and shrubs were planted in the narrow available riparian zone from Bedford Street to the mouth of the Mully Grub.

According to the student conceptual plan, the "powerhorse" of the restoration project was to be the constructed wetland/retention pond, which was to capture pollutants as water was conveyed from the Mully Grub into the wetland. This wetland was constructed during Phase II of the restoration project; it was located along the upper reaches of the Mully Grub on property generously donated by James Bartoli.

Phase II also included the Letort Spring Run restoration project above and below the Mully Grub confluence, conceived and designed by the PA Boat and Fish Commission and Letort Regional Authority. This project included: 1) stone deflectors, to increase the rate of flow, 2) cedar tree brush deflectors, to trap sediment to restore habitat, 3) replacement of streambank stone walls with rock, to allow for more natural stream migration, and 4) construction of wheelchair-accessible pathways, fishing ramps and nature trails in Letort Park, to increase use of the park by all potential users.

One of the keys to the success of the Mully Grub restoration project lies in the meaningful involvement of a wide variety of community stakeholders, with strong coordination from Lauren Imgrund, the ALLARM Director. During both phases of the restoration project, student staff members of ALLARM conducted widespread community education and outreach activities. These activities included: 1) visiting elementary school classrooms to inform the children about the project and to have the students plant and nurture trees for the riparian zone through the winter months, 2) planning and implementing public meetings to solicit ideas from the community and support for the project, 3) organizing the riparian zone planting day, 4) making multi-media public presentations to college and community organizations, 5) making educational signs for the site, 6) providing numerous tours for visitors from the college, government agencies, and the community, 7) doing storm drain stenciling with high school and scouting groups, and 7) holding an ongoing series of clean-up, additional planting, and information days for the community.

Assessment of the project is ongoing and will take years to complete. An assessment protocol is planned or is in place for each of the original goals of the project. Assessment projects include water quality testing during and between storms, annual sediment analyses, with a focus on sites surrounding the wetland, assessments of channel morphology and instream habitat, assessment of ecosystem functionality using biotic indicators, assessment of growth and mortality of riparian zone trees and shrubs and wetland plants, and assessment of the community's response to the project. In addition, to fulfill the goal of providing a model for other community-based urban restoration/mitigation projects, ALLARM faculty and staff have been actively disseminating information on the Mully Grub project through presentations and papers at professional conferences nationwide, and have used it recently as a focus for training activities for a group of visiting Russian scholars and environmental activists.

OVERVIEW OF PROJECT

Environmental mitigation and restoration projects are currently taking place across the country, providing a need for collaboration of a wide array of stakeholders and technical experts or "service providers" (for example, Kauffman et. al 1997, Schueler and Holland 2000, Bohn and Kershner 2002). Such purposeful human intervention into natural systems has the potential of resulting in increased functionality of perturbed systems; these activities also have the potential to increase public awareness and build community capacity for sound stewardship of local resources (West 2000, Wilderman et al. 2003, Ely 1999). One model for collaboration involves partnerships between community members and local colleges/universities. These partnerships have great potential for effective outcomes, but also pose significant challenges (Wilderman 1999, Wilderman et al. in press).

The following paper will document a stream restoration/mitigation project within the Letort Spring Run watershed in Cumberland County, PA (Figure 1), that has involved a strong partnership between the Environmental Studies Department at Dickinson College and the community of Carlisle, PA (Wilderman 2003). During this partnership, the community defined the problem and the research agenda, the College designed and implemented the study, and the community and College collaborated in turning the information into action. (Table 1).

Who defined the problem and the study agenda?	**Who designed the study?**	**Who collected the data?**	**Who analyzed the data?**	**Who turned the data to information?**	**Who decided on what action to take?**	**Who took the action?**
Community groups, such as Trout Unlimited and the Letort Regional Authority	Students and faculty in the ES Department, in consultation with community groups	Students and faculty in the ES Department	Students and faculty in the ES Department	Students and faculty in the ES Department, ALLARM	Community groups in consultation with ALLARM	Local school students, professional consultants and contractors, ALLARM, community groups, individual community members, college employees and students

Table 1. A summary of roles and key players in the scientific study and mitigation project.

This project grew out of a concern expressed by the community regarding the impact of stormwater runoff from the town of Carlisle on the ability of the Letort Spring Run to support a native brown trout fishery throughout its extent. Students, under the supervision of Professor Candie C. Wilderman, first scientifically documented the impact of urban runoff into the Letort Spring Run (Wilderman et al. 1994, Wilderman et al. 1997), and then later focused on the outfall of primary concern to the community -- a small tributary known as the Mully Grub. Students designed a conceptual mitigation plan for the Mully Grub and presented their results and plan to a number of community stakeholders.

In an effort to move forward to implement the mitigation plan, the community developed a partnership with the Alliance for Aquatic Resource Monitoring (ALLARM), a project of the Environmental Studies Department at Dickinson College, which provides technical and programmatic support to watershed groups throughout the state of PA (Wilderman et al. in press). ALLARM was able to secure funding for several mitigation and restoration projects on both the Mully Grub and the Letort Spring Run in the vicinity of the confluence, from a variety of sources, including the PA Department of Environmental Protection. The project was implemented and is being maintained and assessed by a cooperative effort of community groups and individuals, professional contractors, and College employees and students.

After providing the geographical and historical context for this project, PART I will cover the results of the scientific study that established the need for action. PART II will document the collaborative efforts involved in the funding, planning, implementation, maintenance, dissemination, and assessment of the mitigation project.

PART I. THE STUDY

INTRODUCTION

Geographic context

The Letort Spring Run, long renowned as one of the nation's most challenging and productive trout fisheries, is a tributary of the Conodoguinet Creek, which flows into the Susquehanna River just north of Harrisburg, PA (Figure 1). The Letort provides surface drainage for 55.4 square kilometers of Cumberland County, PA. Included in the watershed are large portions of three essentially rural townships (South Middleton, North Middleton and Middlesex), a small area of Dickinson Township, and most of the Borough of Carlisle. The Letort begins in South Middleton Township as a spring-fed high quality cold water fishery (HQ-CWF) creek, with a native brown trout population. Through its 15.3-kilometer journey to its confluence with the Conodoguinet Creek during which it drops an average of 3.4 m per kilometer (Pennsylvania Department of Environmental Resources 1988), it travels through a commercial watercress production facility, past a rather large limestone quarry, under Interstate 81, through the town of Carlisle where it receives urban runoff from at least 4 major outfalls, past the Carlisle Army War College campus, through farmlands, and finally, through the Middlesex Township trucking area near the intersection of the PA Turnpike and Route 81. A portion of the Letort Spring Run, upstream from the urban area, has been designated as Exceptional Value (EV) Waters, and the PA Fish and Boat Commission has placed the Letort Spring Run in the Pennsylvania Scenic Rivers System (Skelly and Loy, Inc. 2000).

The birth of the study

Although the upstream section of the Letort Spring Run is designated as exceptional value by the state, and is known nationally for its excellent brown trout fishery, the middle and lower portions have been moderately impaired from various land use activities in the watershed, and some areas do not currently support a naturally-

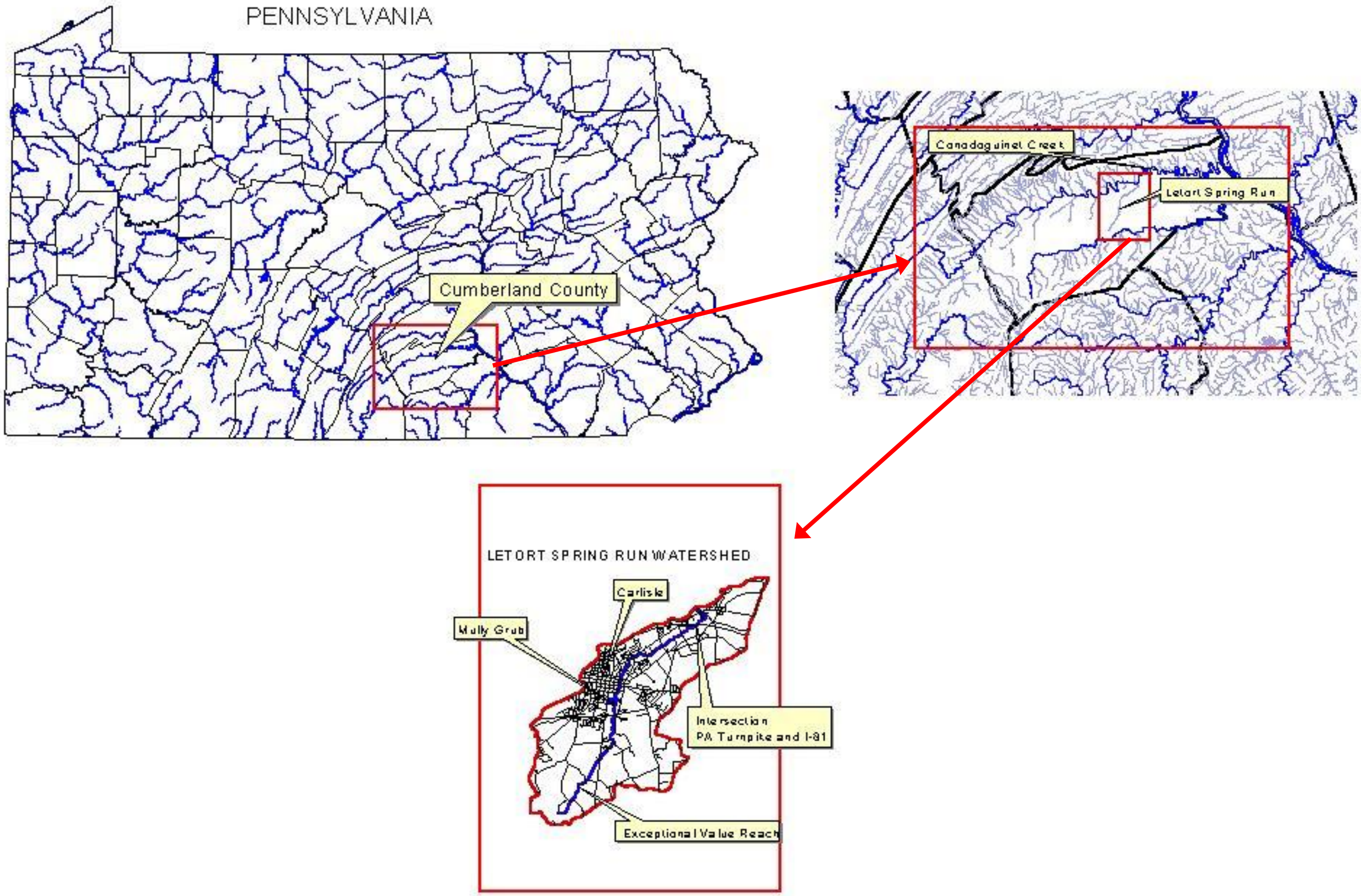


Figure 1. Maps showing the location of the Letort Spring Run Watershed, Cumberland County, PA.

reproducing brown trout population (Skelly and Loy, Inc. 2000). Two recent studies have specifically assessed the stormwater runoff pollutant load from various land uses in the Letort Spring Run watershed (Wilderman et al. 1994, Wilderman et al. 1997). In particular, these studies focused on 22 pollutants and four land uses: agriculture, suburban, urban, and trucking activities. These studies revealed that on a per-acre basis, the largest contributor of total pollutants to the receiving stream is the trucking land use area, followed by the urban land use area, the suburban land use area, and finally the agricultural area. These pollutants were also shown to be having an adverse impact on the Letort Spring Run, based on surveys of macroinvertebrate populations, diatom communities, vegetation and sediment pollution. All of these factors indicate impaired waters in the sections of the Letort receiving urban runoff when compared to the more pristine headwaters. In general, these studies corroborate similar studies on urban and highway runoff in other regions (for example, Cole et al. 1984; Nezil-Salvaggio et al. 1990; Center for Watershed Protection 2003).

In 1998, the Letort Regional Authority[1], recognizing that the more pristine upstream segments of the Letort are not accessible to all anglers due to the rather rough terrain, proposed to build an access ramp for handicapped anglers in the section of the Letort which flows thorough Letort Park, a well-utilized urban park in the town of Carlisle (Figure 2). The proposed plan also included enhancement of instream habitat to support trout populations.

The proposed project is located in the section of the Letort immediately downstream from the Mully Grub, a natural, groundwater-fed tributary which has been channeled into storm drains as the town of Carlisle has grown over and around it.[2] The examination of old maps at the Cumberland County Historical Society revealed that the Mully Grub existed as a single channel as far back as the oldest map found, drawn in 1867 (Strong 1867).[3] The Mully Grub now collects and conveys urban runoff from a large subwatershed to the Letort Spring Run; it empties into the Letort just upstream from the proposed project (Figure 2). For this reason, the Letort Regional Authority expressed some concern that the effects of the Mully Grub might need to be mitigated to ensure that the project area did not become degraded by urban runoff during storm events.

[1] The Letort Regional Authority consists of two voting members from each of the municipalities and townships in the watershed. The purpose of the Authority is to improve and protect water quality, flow, and recreational opportunities on the Letort, by reviewing proposed projects and engaging in long-term planning. It has been involved in numerous activities since 1974 in cooperation with government agencies, citizens' groups, local schools, and colleges to manage the health of the stream and maintain it as a community resource.

[2] According to the Dictionary of American Regional English (Cassidy and Hall 1996) the term mulligrub is defined as: 1) "a tadpole," 2) "an insect larvae, such as a hellgrammite", and 3) when plural, "a condition of despondency or ill temper: a vague or imaginary unwellness."

[3] An older map from 1768 does not show the Mully Grub; however, maps from 1867 and 1872 both show the tributary in its present configuration downstream from Hanover St., but with a large sub-aerial upstream section, extending approximately 0.8 km from where it currently emerges from the storm drain system. Local residents also report the presence of a shallow spring-fed lake in the headwater area, used for ice-skating until urban development obliterated it in the 1960's.

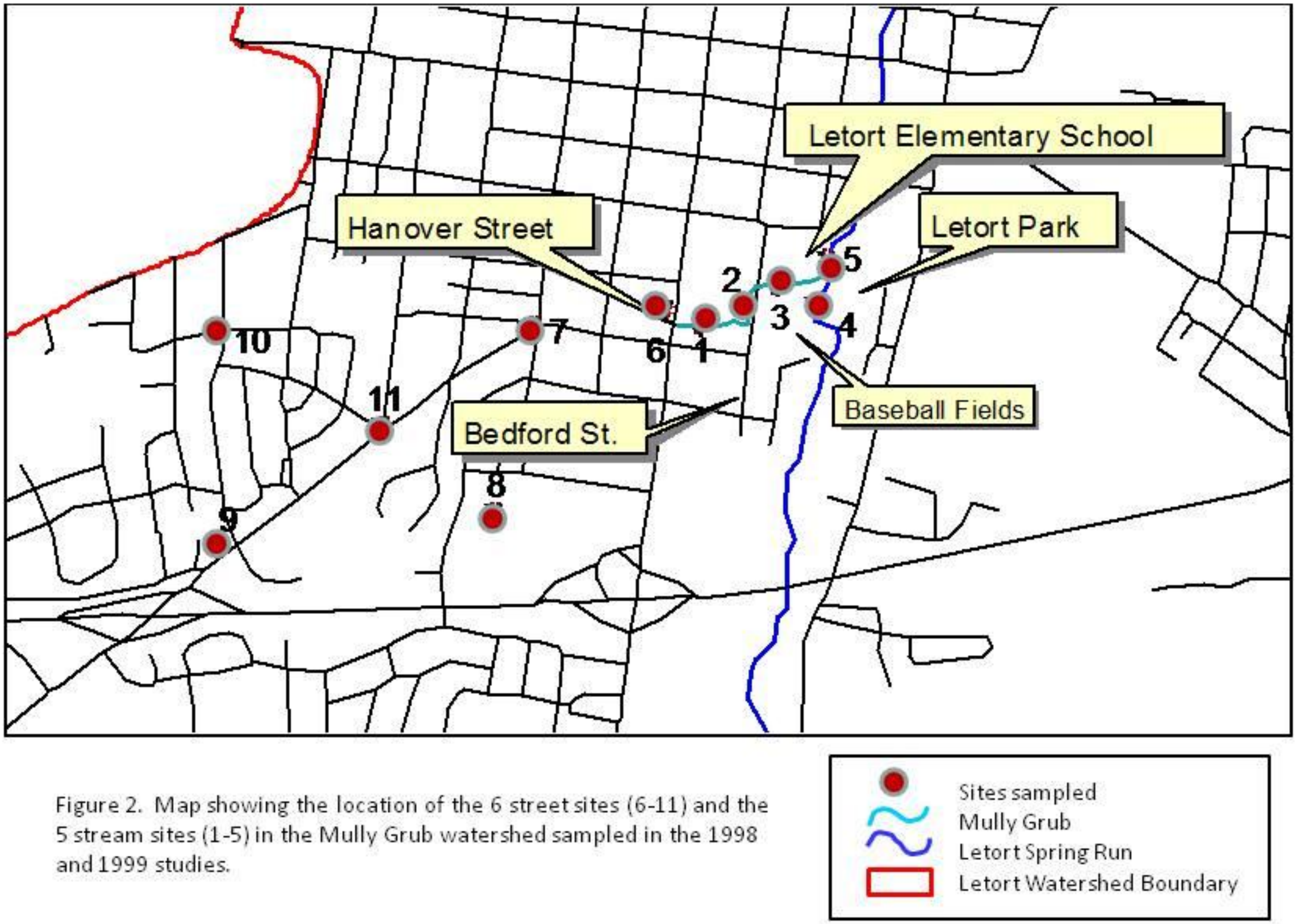


Figure 2. Map showing the location of the 6 street sites (6-11) and the 5 stream sites (1-5) in the Mully Grub watershed sampled in the 1998 and 1999 studies.

It was out of this concern expressed by the community that a decision was made by students and faculty from the Environmental Studies Department at Dickinson College, in Carlisle, PA to conduct a two-year study. The objectives of the study were: (1) to achieve an assessment of the water quality of the stormwater runoff that flows from the town of Carlisle into the Mully Grub, (2) to assess the cumulative effects of this runoff on the Mully Grub and on the Letort Spring Run just downstream from the confluence in the proposed project area, and (3) to suggest ways to mitigate these effects to insure that proposed restoration and enhancement efforts on the Letort Spring Run are protected from future degradation.

METHODOLOGY

This study was conducted during the spring semesters of 1998 and 1999, (from January, 1998 through May, 1998 and from January, 1999 through May, 1999) by students in the Department of Environmental Studies at Dickinson College, as part of the requirements for completing an intermediate-level Environmental Science course, taught by Prof. Candie C. Wilderman. The study was supervised by Dr. Wilderman, with the assistance of Mr. Mark S. Kauffman, Academic Technician for the Environmental Studies Department. The list of student, faculty and staff participants follows the title page of this document.

Sampling Design

The locations, the dates sampled, and the parameters measured at the 11 study sites are shown in Figure 2 and Tables 2 and 3. Figure 3 depicts the multiple lines of evidence or indicators that were used in this study to document the impact of urban runoff on the study area.

Sites 1-5 are instream sites, located in the Mully Grub and in the Letort Spring Run, just upstream and downstream from the Mully Grub confluence. These five sites were sampled and analyzed for 21 chemical parameters during 3 storm events in 1998-1999; they were also sampled between storm events (closer to base flow) in both years. These instream sites were also evaluated for sediment chemical composition, macroinvertebrate community composition, diatom community composition, meiofauna community composition, habitat, and channel stability (Table 2).

The other 6 sites (Sites 6-11) are located on the streets, where stormwater accumulates from paved surfaces and from highway runoff throughout the Mully Grub subwatershed. Sites 6-8 are in densely populated areas with a high amount of vehicular traffic, whereas sites 9-11 are in areas of medium residential density and are therefore considered to be suburban. These street sites were only sampled in 1998, and were analyzed for the same 21 chemical parameters as the instream sites (Table 3).

Site	Description of InstreamSite	Indicators measured												
		Water Chemistry					Seds	Macro-invertebrates		Diatoms	Meiofauna	Habitat	Channel Stability
		3/6/98	**3/1/98**	**4/9/98**	**2/28/99**	3/22/99	3/2/98	3/2/98	3/22/99	3/9-3/23/98	4/12-19/99	3/22/99	3/22/99
1	Hanover St. outfall	x	x	x	x	x	x	x	x	x	x	x	x
2	near Bedford St. at bend				x	x	x	x	x	x		x	x
3	reach near baseball fields	x	x	x	x	x	x	x	x	x	x	x	x
4	Letort, upstream from MG	x	x	x	x	x	x	x	x	x	x	x	x
5	Letort, downstream from MG	x	x	x	x	x	x	x	x	x	x	x	x

Table 2. Site descriptions, indicators measured, and dates sampled at instream sites in the Mully Grub and Letort Spring Run, 1998-1999.

bold date = runoff event

Site	Description of Street Site	Water Chemistry on Street Runoff	
		3/8/98	**4/9/98**
6	Hanover St., near car wash across from Wendy's	x	x
7	Y intersection: Walnut Bottom, Willow, and West Sts.	x	x
8	MG Mall parking lot	x	x
9	3-pipe outfall along Walnut bottom Rd., west of Rt. 81	x	x
10	Intersection of Hillside and Belvedere Rds.	x	x
11	Intersection of Walnut Bottom Rd. and Morreland St.	x	x

Table 3. Site descriptions and dates that stormwater runoff was sampled on streets in the Mully Grub watershed.

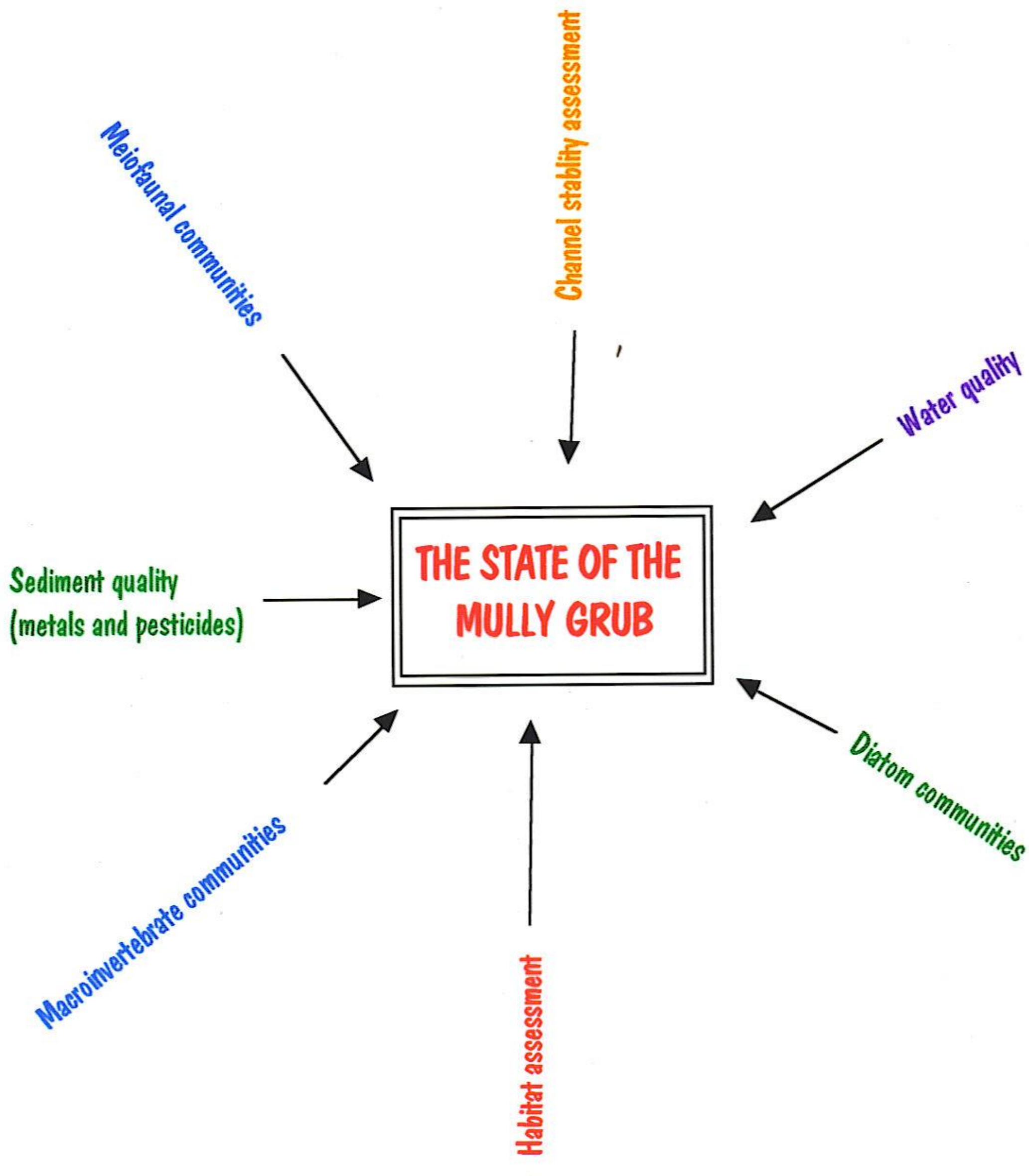


Figure 3. Chart showing multiple lines of evidence used in the 1998-99 studies to assess the state of the Mully Grub.

Stormwater Study Sampling Methods

Table 4 is a list of the chemical parameters measured at each of the 11 sites during the stormwater events, along with the bottle preparation procedure, the sampling protocol, and the methods used for analysis. The class divided into five sampling teams, each covering 2-3 sites. Bottles were prepared ahead of time and a central person was designated to activate the sampling procedure if the runoff event was significant and the timing was practical. Each team collected water in all of the separately prepared bottles and returned them to the laboratory for proper storage. Analysis teams (different from the sampling teams) were then responsible for the laboratory analysis of certain parameters, using a single procedure on all of the sites from which water was collected. Analysis teams were also responsible for preparing fresh bottles for the next sampling.

Instream Study Sampling Methods

In addition to the water samples collected during storm events, samples were also collected from the 5 designated instream sampling sites in the Letort Spring Run and the Mully Grub (Figure 2, Table 2) for analysis of the same 21 chemical parameters (Table 4) during a dry period between storm events.

Sediment samples were collected from the 5 instream sites on March 2, 1998 (Figure 2, Table 2). Sediments were analyzed for total petroleum hydrocarbons, pesticides, and for selected metals (Fe, Mn, Cu, Pb, Ni, Cr, Cd, Al). Separate sampling protocols were followed for each group of analytes.

For the analysis of organics, sediments were collected using stainless steel trowels and mixing bowls, prepared with FL-70 soap, methanol, and deionized water. Muddy sediments were collected at each site, mixed to form a composite in a large stainless bowl and put into brown glass bottles. They were iced and delivered to Pennsylvania Department of Environmental Protection (PA DEP) laboratories, who performed the analyses. Pesticides were measured using US EPA Method 608, "Methods for Chemical Analysis of Water and Wastes", Federal Register vol. 49, no. 209, October 26, 1984. Petroleum hydrocarbons were measured by a method based on US EPA SW-846, "Test Methods for Evaluating Solid Waste", 3rd Edition; Methods 8000, 8015, and 8100, and work by Rhodes, et al. (1991) (Gary Manczka, personal communication).

For the analysis of metals, sediments were collected using plastic trowels and buckets prepared with FL-70 soap. These sediments were also composited and put into plastic bottles, iced, and brought to DEP laboratories for analysis. Methods used to measure metals were based on US EPA SW-846, "Test Methods for Evaluating Solid Waste", 3rd Edition; Methods 3050A and 6010A (Gary Manczka, personal communication).

Macroinvertebrates used in this analysis were collected from the 5 instream sites on March 22, 1999 (Figure 2, Table 2), using a one square meter kick seine. Riffle areas were chosen, where possible, because they generally provide the most diverse community

Parameter	Bottles and bottle preparation	Sampling protocol	Laboratory analysis protocol
Aluminum Cadmium Chromium Copper Iron Lead Manganese Nickel Zinc	250-ml poly, wide-mouth bottles, double washed with nitric and HCl acid, 2% concentrated nitric acid added; Bottles weighed before acid added, after acid added, and after sample added to calculate dilution by nitric acid.	Scooper bottles were rinsed three times with the water to be sampled, filled, and then the water was pouted into the bottle with the nitric acid, and capped tightly.	Samples analyzed using a Varian graphite furnace atomic absorption spectrophotmeter or a Varian flame atomic absorption spectrophotometer, depending on concentration of the analyte.
Fecal coliform or Total coliform	250-ml glass-stoppered glass bottles, autoclaved.	Without handling the inside of the bottles, they were filled with water and stoppered tightly.	Samples analyzed using the standard Millepore membrane filtration method. (0.01, 0.1 and 1 ml of sample were filtered to derive the appropriate volume to use.) Depending on the target organism, samples were incubated at the appropriate temperature, using the appropriate agar medium. A few samples, extremely high in suspended solids were filtered through a coarse filter prior to analysis.
Total suspended solids Total dissolved solids	500-ml poly, wide-mouth bottles; scrubbed thoroughly with soap.	Bottles were rinsed three times, filled, and stoppered tightly.	2 150-ml samples were filtered through glass filters and the filters dried and weighed for suspended solids. Filtrate was evaporated in ovens and precipitate weighed for dissolved solids.
Phosphate (reactive) Nitrate-nitrogen Ammonia-nitrogen	500-ml poly, wide-mouth bottles; washed and acid-rinsed (HCl)	Bottles were rinsed three times, filled, and stoppered tightly. Bottles were refrigerated and analyzed within 24 hours of collection.	Ascorbic Acid Method, HACH Spec 2000 Cd reduction method, HACH Spec 2000 Nessler method, HACH Spec 2000
BOD	250-ml glass-stoppered glass bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	YSI 5905 BOD probe
Conductivity	500-ml poly, wide-mouth bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	YSI Model 33 S-C-T meter
Alkalinity	500-ml poly, wide-mouth bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	HACH method 8203; Sulfuric Acid Digital Titration Method
pH	500-ml poly, wide-mouth bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	LaMotte pH meter, Model HA
Hardness	500-ml poly, wide-mouth bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	EDTA Digital Titration Method
Chloride	500-ml poly, wide-mouth bottles, cleaned thoroughly.	Bottles were rinsed three times, filled, and stoppered tightly.	Silver Nitrate Digital Titration method

Table 4. Description of preparation, sampling and laboratory protocol for water chemistry analyses performed.

(Barbour et. al 1999). Initially, all macroinvertebrates were removed manually from rocks in a one square meter area and then the stream bottom was disturbed by kicking to a depth of 5 centimeters. All organisms were removed from the net and placed in bottles containing ethanol. Macroinvertebrates were then identified to the family level and all individuals from a given sample were enumerated in the laboratory.

The macroinvertebrates collected during this study were compared to samples taken by previous student researchers in 1995 (Wilderman et al. 1997) in the upstream, urban, and trucking segments of the Letort Spring Run. There were a total of 18 sites sampled and analyzed -- five from the upstream reach, three from the Mully Grub, six from the urban reach, and four from the trucking reach.

Habitat assessments were performed at the same 5 sites from which macroinvertebrates were collected in 1999, using the EPA protocol for both muddy and rocky bottom streams (United States Environmental Protection Agency 1997). The Letort Spring Run site upstream from the confluence was used as the reference site in this evaluation.

Channel stability analysis was also conducted in 1999 at the same 5 sites used in evaluating macroinvertebrate communities and habitats (Table 2, Figure 2). The Pfankuch channel stability assessment was used (Pfankuch 1975). This assessment evaluates the characteristics of the upper banks, lower banks, and bottom of the stream bed to indicate channel stability. An overall score is calculated and ranked on an absolute scale, without a comparison to reference sites. Recently Rosgen (1996) has adjusted this absolute scale to take into account stream types, and thereby to convert channel stability ratings to reach conditions; this Rosgen modification was not used in the present analysis.

Diatoms were collected by placing a periphyton sampler (Patrick et al. 1954), consisting of an apparatus for holding 8 glass slides upon which diatom colonization occurs, at each of 5 instream sites in the Mully Grub and the Letort Spring Run (Figure 2, Table 2). The samplers were attached to cinder blocks and placed on the stream bottom. Locations of similar velocity, depth, and temperature regimes were chosen for the placement of these artificial substrates. The samplers were left in the stream for 2 weeks, from March 9, 1998 to March 23, 1998.

After two weeks of immersion of the samplers, diatoms were scraped off of the glass slides and refrigerated. The material was processed by adding hydrogen peroxide and potassium dichromate to oxidize the organic matter and then by washing the solution several times (Hanna 1930). All slides were scanned at 1000x magnification under oil immersion using an Accu-Scope light microscope. At least 50 tests at each site were identified to the genus level (Patrick and Reimer 1966, 1975, Hustedt 1939) and enumerated.

Samples were collected for the analysis of meiofaunal communities at sites 1 and 3 in the Mully Grub and sites 4 and 5 in the Letort Spring Run on April 12 and April 19, 1999 (Figure 2, Table 2). At each site, three cores of the bottom sediment were extracted using a 30 cc syringe with a diameter of 2 cm and with the needle end removed. With the plunger down, the corer was placed near the surface of the substrate; the tube was then pushed down into the substrate while the plunger was held in place at the surface. The core was expunged into a glass jar (Higgins and Thiel 1998).

Meiofaunal organisms were extracted from the sediment using a combination of flotation and bubbling techniques (Thorp and Covich 1991, Heip et al. 1974). Organisms were removed from the sample by blotting the surface with paper. The paper was rinsed with deionized water into a 38um sieve, which was backwashed into a small petri dish. Organisms were identified and enumerated using a compound microscope at 40x and 100x magnification.

Data Analysis Methods

All data were subjected to standard statistical analysis and graphs were produced using Microsoft Excel on a Macintosh PowerPC.

Street sites (sampled in 1998) were ranked by standardizing the average concentrations of all pollutants at each site, utilizing the normalized value z, where z is equal to the average concentration of the pollutant at that site (measured during the 2 storm episodes) minus the average concentration of the pollutant at all 6 street sites sampled and divided by the standard deviation of the concentration of the pollutant at all 6 street sites. These standardized concentrations of all parameters (z-scores) were then summed for each site; sites with the highest overall scores were considered to be the most polluted sites. This method does not weigh the various pollutants based on their toxicity or known effects to the environment, but gives equal weight to all parameters measured. In scoring sites for comparison purposes, the following parameters were not included in the scores: 1) parameters with missing data at some sites, 2) parameters which are not necessarily indicators of pollution, such as alkalinity and pH, and 3) more than one of any multiple parameters that tend to be redundant, for example, conductivity and dissolved solids.

Similarly, to compare the overall pollutant concentrations in the 2 runoff events sampled in 1998, concentrations of all major pollutants were averaged over all sites within each sampling period. Those concentrations were then z-normalized and summed to give a total score for each sampling period. The sampling date with the highest score was considered to be the runoff event with the highest concentration of pollutants.

Macroinvertebrate communities were analyzed using data analysis techniques described for the EPA Rapid Bioassessment Protocol (RBP) II (Barbour et al. 1999), which integrates several community, population and functional parameters into a single evaluation of biotic integrity. Parameters calculated were Taxa Richness, Modified (Hilsenhoff) Biotic Index, Ratio of Scrapers to Filter Collectors, Percent Contribution of Dominant Family, EPT Index, Community Loss Index and Ratio of Shredders to Total Taxa. The ratio of EPT and Chironomidae Abundances was not calculated because of the overall minor occurrence of the Chironomidae. The seven parameters calculated were used in the bioassessment and also in a direct comparison of all reaches sampled. The reaches were then categorized as to the level of impact based on a consideration of all metrics.

Relative abundance of meiofaunal organisms was calculated for each of the sampling dates and for both dates pooled. The Pielou transformation of the Simpson diversity index was used to estimate heterogeneity for each sample. This index is most sensitive to changes in more abundant species (Krebs 1989). Student t-tests were also performed to test the significance of differences between sampling dates and sites.

RESULTS AND INTERPRETATION

Comparison of stormwater runoff at street sites in the Mully Grub Watershed

Table 5 and Figure 4 show the average concentrations of all analytes measured at the 6 street sites in the watershed during the two storm events in 1998. Total scores of each site, based on a standardization of all chemical data are also reported in Table 5 and then listed in order of increasing water quality in Table 6.

Site rankings indicate that the most impacted sites are the two sites in the most urban section of the watershed; the least impacted sites are located in the most suburban areas where lower density housing is found. In fact, the ranking of sites from most impacted to least impacted falls along a gradient of decreasing area paved and decreasing vehicular activity, indicating that the pollutants in the stormwater runoff are closely related to the amount of vehicular activity in the area surrounding the sampling sites. These results corroborate the results of a study in the Santa Clara Valley, CA which concluded that cars are the leading source of metal loads in the state (Schueler and Holland 2000).

Table 7 and Figure 5 place the stormwater study on the Mully Grub within the context of other related studies done in the Letort Spring Run watershed (Wilderman et al. 1994, 1997). Total z-scores indicate that the Mully Grub watershed is the least polluted of all street areas in the comparison studies, but significantly more polluted than the agricultural areas and the upstream Letort. Figure 5 also shows that the trucking area streets in Middlesex Township are the most polluted, followed by the Carlisle urban area, then the Carlisle suburban area, the Mully Grub watershed area, the agricultural area, and finally, the upstream Letort instream sites.

One reason that the Mully Grub watershed has relatively less polluted runoff than the other comparable street areas may be the fact that the winter of 1998 had almost no snowfall. In both 1995 and 1996, when the other areas were sampled, one of the stormwater runoff events included a significant amount of melting snow, which carried a large amount of dissolved road salts. Neither of the 1998 runoff events carried melted snow. Several of the parameters that contribute to the overall pollution status of the

Composite average concentrations (3/9/98 and 4/10/98)

Site	NO3 (ppm)	NH3-N (ppm)	Reac. P (ppm)	Cond (umohs)	Alk (ppm)	pH	Chloride (ppm)	BOD (ppm)	FC (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppm)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppm)
#6-Hanover St.	0.375	0.693	0.083	85.0	40.0	6.35	3.0	8.96	419	1740.0	100.0	0.60	6.24	9.91	0.660	57.35	41.53	3.06	0.170
#7-Y inter	0.425	1.080	0.048	102.5	45.0	6.35	6.0	5.43	932	148.3	90.0	1.15	42.63	8.03	0.370	23.70	45.42	2.38	0.119
#8-MJ Mall	0.500	0.783	0.015	85.0	40.0	6.60	1.1	1.62	250	1700.0	165.0	0.50	5.21	5.21	0.870	24.65	89.22	1.06	0.064
#9-3-pipe	0.250	0.578	0.053	107.5	35.0	6.45	12.5	1.95	145	23.3	55.0	0.40	3.16	5.23	0.155	5.75	12.94	0.36	0.118
#10-Hill/Bel	0.525	0.703	0.065	55.0	37.5	6.55	2.3	3.11	100	1626.7	48.4	0.20	3.19	5.85	0.345	7.15	26.94	0.97	0.033
#111-Wal/Moore	0.625	1.113	0.048	85.0	50.0	6.25	3.9	6.59	314	253.4	58.4	0.55	5.34	8.14	0.605	22.80	66.52	1.54	0.087
AVERAGE	0.450	0.825	0.052	86.7	41.3	6.43	4.8	4.61	360	915.3	86.1	0.57	10.96	7.06	0.501	23.57	47.09	1.56	0.098
ST DEV	0.13	0.22	0.02	18.42	5.42	0.13	4.10	2.89	302.71	851.36	43.81	0.32	15.56	1.92	0.26	18.60	27.42	1.00	0.05

Standardized matrix (z-scores)

SITE	NO3	NH3-N	Reac. P	Cond	Alk	pH	Chloride	BOD	FC	TSS	TDS	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	*TOTAL SCORE
#6-Hanover St.	-0.58	-0.60	1.38	-0.09	-0.23	-0.56	-0.43	1.51	0.20	0.97	0.32	0.10	-0.30	1.48	0.62	1.82	-0.20	1.50	1.49	9.26
#7-Y inter	-0.19	1.16	-0.19	0.86	0.69	-0.56	0.30	0.28	1.89	-0.90	0.09	1.83	2.03	0.50	-0.51	0.01	-0.06	0.82	0.43	7.50
#8-MJ Mall	0.38	-0.19	-1.64	-0.09	-0.23	1.31	-0.90	-1.03	-0.36	0.92	1.80	-0.21	-0.37	-0.96	1.43	0.06	1.54	-0.50	-0.72	-0.76
#9-3-pipe	-1.53	-1.12	0.04	1.13	-1.15	0.19	1.87	-0.92	-0.71	-1.05	-0.71	-0.52	-0.50	-0.95	-1.34	-0.96	-1.25	-1.21	0.40	-10.46
#10-Hill/Bel	0.58	-0.55	0.60	-1.72	-0.69	0.94	-0.61	-0.52	-0.86	0.84	-0.86	-1.15	-0.50	-0.63	-0.60	-0.88	-0.74	-0.60	-1.36	-7.85
#111-Wal/Moore	1.34	1.31	-0.19	-0.09	1.61	-1.31	-0.23	0.68	-0.15	-0.78	-0.63	-0.05	-0.36	0.56	0.40	-0.04	0.71	-0.02	-0.24	2.31

* did not use Cond, Alk, or pH for reasons stated in methods section.

Table 5. Composite average concentrations of all parameters at all street sites in the Mully Grub subwatershed, z-scores, and total scores for the purpose of comparing sites.

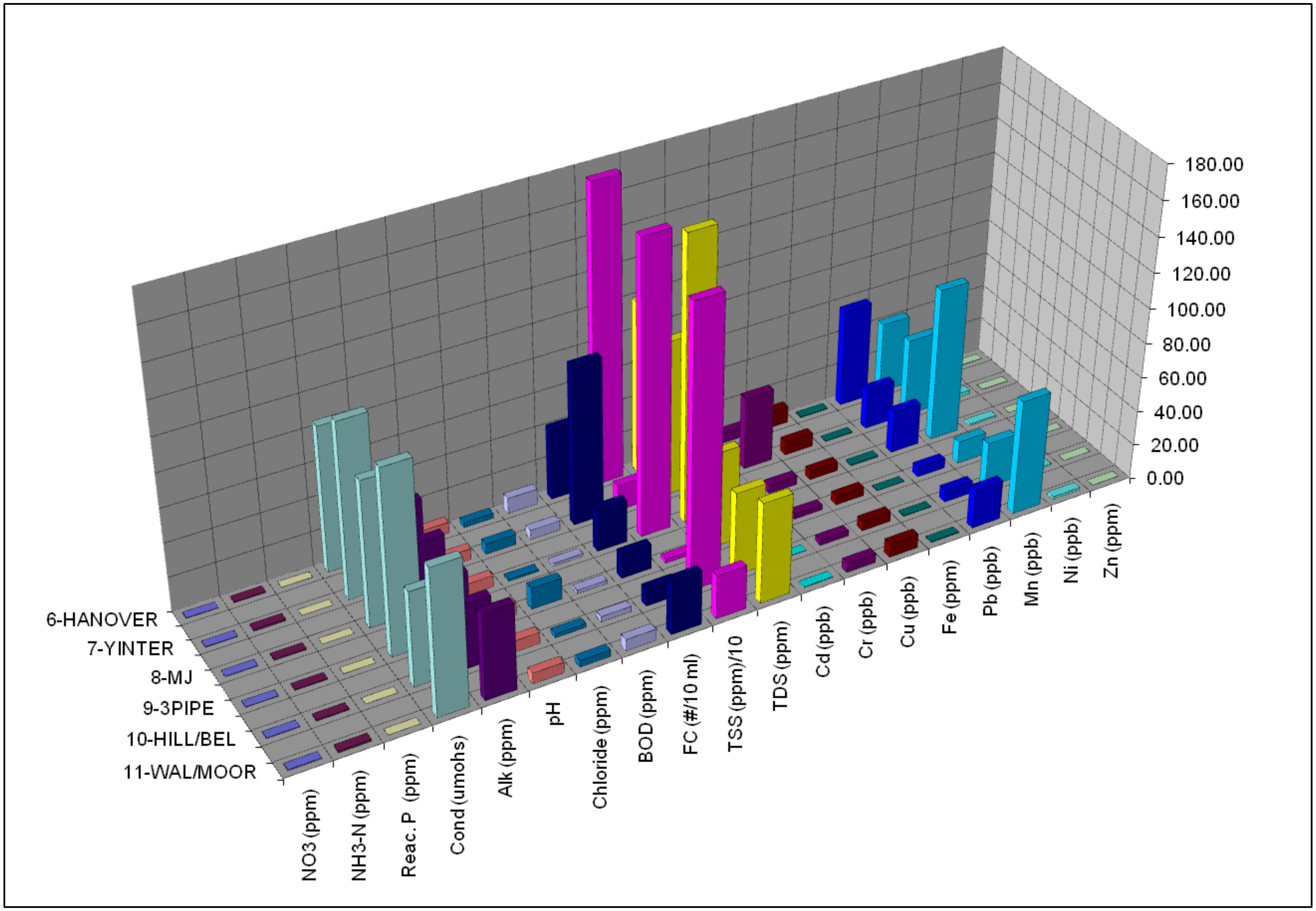


Figure 4. Average concentration of all analytes at the 6 street sites.

SITE NUMBER	ACRONYM	SITE LOCATION	PREDOMINANT LAND USE	RANK	SCORE
6	HANOVER	Hanover St., near car wash	urban	1	9.26
7	YINTER	Y intersection, Walnut Bottom, Willow and West	urban	2	7.50
11	WAL/MOOR	Intersection of Walnut Bottom Rd. and Mooreland St.	urban/suburban	3	2.31
8	MJ	MJ Mall parking lot	urban/suburban	4	-0.76
10	HILL/BEL	Intersection of Hillside and Belvedere Rds.	suburban	5	-7.85
9	3PIPE	3-pipe outfall along Walnut Bottom Rd., west of Rt. 81	suburban	6	-10.46

Table 6. List of all stormwater sampling sites in order of increasing water quality, based on all pollutants measured during two storm events in 1998. See text and Table 5 for explanation of method used in ranking sites.

Composite average concentrations (1993-98)

	Mully Grub watershed 1998 (N=6)	Carlisle, PA (urban) 1993 (N=6)	Carlisle, PA (suburban) 1993 (N=4)	Middlesex,PA (trucking) 1995-96 (N=8)	Middlesex,PA (agricultural) 1995-96 (N=2)	Upstream Letort (N=13)	AVERAGE	STANDARD DEVIATION
Al (ppm)	ND	2.0	1.7	2.5	0.8	0.2	1.4	0.93
Alkalinity (ppm)	41.3	97.9	72.7	121.0	205.9	200.0	123.1	67.30
BOD (ppm)	4.6	6.9	7.5	7.7	3.4	1.1	5.2	2.64
Conductivity (umohs)	86.7	1229.8	1300.0	658.8	461.5	404.0	690.1	482.18
Cr (ppb)	11.0	8.3	3.7	18.4	2.3	0.9	7.4	6.59
Cu (ppb)	7.1	13.5	7.2	29.2	4.8	0.5	10.4	10.13
Cl (ppm)	4.8	375.3	344.3	272.8	102.0	48.2	191.2	159.47
Dissolved Solids (ppm)	86.1	694.4	483.3	382.1	232.8	335.7	369.1	209.21
Fe (ppm)	0.5	3.6	3.4	4.0	0.64	0.52	2.1	1.70
Fecal Coliform (#/100 ml)	359.8	98.8	38.8	6269.8	2610.0	321.3	1616.4	2477.48
Total Hardness (ppm)	ND	65.6	47.0	117.3	277.9	269.0	155.4	110.88
Mn (ppb)	47.1	15.5	7.8	148.5	66.8	3.1	48.1	55.03
NH3 (ppm)	0.825	0.580	0.670	1.850	0.410	1.410	1.0	0.56
Ni (ppb)	1.6	5.1	4.0	5.6	0.8	0.2	2.9	2.34
NO3 (ppm)	0.450	1.320	0.660	0.930	2.370	4.600	1.7	1.56
P (Total) (ppm)	ND	0.320	0.280	0.450	0.490	0.280	0.4	0.10
Pb (ppb)	23.6	34.4	19.0	64.8	16.0	0.6	26.4	21.78
Suspended Solids (ppm)	915.3	149.4	75.0	437.9	239.6	35.0	308.7	329.95
Zn (ppm)	0.098	0.230	0.200	0.350	0.030	0.030	0.2	0.13

Standardized matrix of z-scores

	Mully Grub watershed 1998 (N=6)	Carlisle, PA (urban) 1993 (N=6)	Carlisle, PA (suburban) 1993 (N=4)	Middlesex,PA (trucking) 1995-96 (N=8)	Middlesex,PA (agricultural) 1995-96 (N=2)	upstream Letort (N=13)	
Al (ppm)	ND	0.62	0.33	1.09	-0.68	-1.36	
Alkalinity (ppm)	-1.22	-0.38	-0.75	-0.03	1.23	1.14	
BOD (ppm)	-0.22	0.63	0.87	0.95	-0.67	-1.56	
Conductivity (umohs)	-1.25	1.12	1.26	-0.06	-0.47	-0.59	
Cr (ppb)	0.54	0.14	-0.57	1.66	-0.78	-1.00	
Cu (ppb)	-0.32	0.31	-0.31	1.86	-0.55	-0.97	
Cl (ppm)	-1.17	1.15	0.96	0.51	-0.56	-0.90	
Dissolved Solids (ppm)	-1.35	1.56	0.55	0.06	-0.65	-0.16	
Fe (ppm)	-0.94	0.86	0.75	1.12	-0.85	-0.93	
Fecal Coliform (#/100 ml)	-0.51	-0.61	-0.64	1.88	0.40	-0.52	
Total Hardness (ppm)	ND	-0.81	-0.98	-0.34	1.11	1.02	
Mn (ppb)	-0.02	-0.59	-0.73	1.82	0.34	-0.82	
NH3 (ppm)	-0.24	-0.68	-0.52	1.61	-0.99	0.81	* does not include Al,
Ni (ppb)	-0.55	0.95	0.49	1.18	-0.91	-1.15	Cond, Alk, Dis Solids,
NO3 (ppm)	-0.81	-0.26	-0.68	-0.51	0.41	1.84	Hard or P for reasons
P (Total) (ppm)	ND	-0.44	-0.85	0.87	1.27	-0.85	stated in methods
Pb (ppb)	-0.13	0.37	-0.34	1.76	-0.48	-1.18	section.
Suspended Solids (ppm)	1.84	-0.48	-0.71	0.39	-0.21	-0.83	
Zn (ppm)	-0.46	0.58	0.34	1.53	-1.00	-1.00	
***TOTAL Z-SCORE**	**-2.99**	**3.48**	**0.18**	**15.70**	**-6.32**	**-8.80**	

Table 7. Average concentrations of common pollutants and z-normalized data used to compare overall pollution status of the Mully Grub subwatershed stormwater runoff in 1998 to other subwatersheds in the Letort Spring Run watershed (Wilderman et al. 1994,1997).

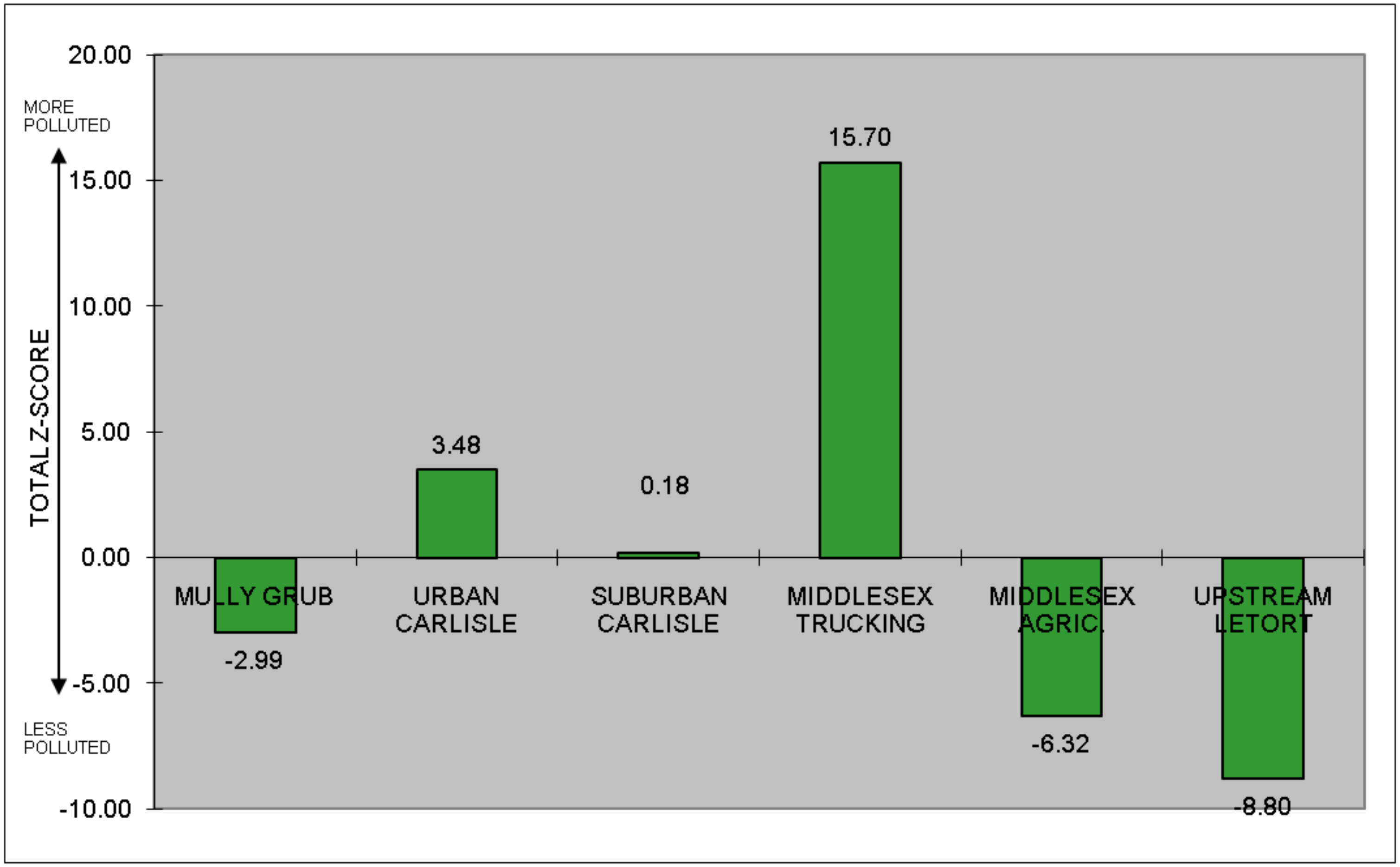


Figure 5. Graph of total z-scores for street sites in the Letort Spring Run watershed. Data are in Table 6.

sampling sites reflect road salt pollution, for example, chloride, dissolved solids and metals (Schueler and Holland 2000). The absence of road salt in the 1998 samples may account for the overall higher water quality in the Mully Grub watershed street sites.

Table 8 compares average concentrations of the major pollutants in the Mully Grub street sites to values reported in the literature outside of the watershed. Values reported in the literature vary widely, as can be ascertained by comparing values reported in two major studies reflected in Table 8 (Cooke et al. 1995[Santa Clara Valley, CA] and Chang et al. 1990 [Austin, TX]). In comparison to national averages, the Mully Grub subwatershed street sites have lower concentrations of most pollutants than sites included in the national averages (Center for Watershed Protection 2003), although the concentrations of many pollutants are close to the national averages. This may be explained by the fact that the subwatershed is in a mixed suburban/urban area and therefore may have less urban land use than the average sites included in the national studies. Exceptionally low values were found for some pollutants associated with organic pollution, such as fecal coliform and BOD, although ammonia-nitrogen was higher than values reported from the Austin, TX study. Metal concentrations were fairly close to ranges reported in the literature, with the exception of nickel, which was very low. As noted above, parameters related to the application of road salts were very low in this study, although suspended solids were unusually high (Table 8).

These comparisons show that activities in the Mully Grub watershed produce pollutants comparable in concentration to other urban and suburban areas, with overall concentrations being closer to residential, suburban areas. These pollutants are ultimately delivered to the Letort Spring Run via the Mully Grub.

Comparison of stormwater events in 1998

Table 9 and Figure 6 show the average concentrations of analytes at the 6 stormwater sites sampled in the Mully Grub watershed during the two stormwater events. Although total z-scores could not be calculated (since only two events were sampled), the event on March 9 was clearly less polluted than the event on April 10, with lower concentrations of all parameters except reactive phosphorus and chloride. This can be explained by the fact that the total rainfall amount during the week prior to the March 9th sampling was more than 4 times higher than the rainfall during the week prior to the April 10th sampling (Table 10). Heavy rainfall prior to a sampling event will cleanse the streets of pollutants; if there is little time for new pollutants to accumulate before another rainfall event, the runoff is likely to carry less pollutants.

This pattern is corroborated by data from 1995 and 1996 as well (Table 10). Although there is no significant correlation between the rainfall on the date of sampling and the severity of the runoff event, the data suggest that there is a negative relationship between the amount of rainfall during the week prior to sampling and the severity of the runoff, as measured by a total z-score ($r = -0.792$ in 1995 and $r = -0.972$ in 1996).

Indicator measured	Average conc, MG street sites, 1998 (urban/ suburban)	Typical national values*	Heavy industrial, Santa Clara Valley (Cooke et al. 1995)	90% imperviousness Austin, TX (Chang et al. 1990)	Residential/ Commercial Santa Clara Valley (Cooke et al. 1995)	30% imperviousness Austin, TX (Chang et al. 1990)
NO3 (mg/L)	0.450	0.530		0.670		0.710
NH3-N (mg/L)	0.825			0.240		0.240
Reac. P (mg/L)	0.052	0.100		0.200		0.220
Chloride (mg/L)	4.8	397.0				
BOD (mg/L)	4.61	11.50				10.00
FC (#/100 mL)	360	15038		31		39
TSS (mg/L)	915.3	67**				
TDS (mg/L)	86.1			123.0		170.0
Cd (ug/L)	0.57	0.70	4.30		1.00	
Cr (ug/L)	10.96	7.00				
Cu (ug/L)	7.06	11.10	50.00	10.00	28.00	10.00
Fe (mg/L)	0.501			0.58		0.68
Pb (ug/L)	23.57	50.70	112.00	60.00	35.00	45.00
Ni (ug/L)	1.56		48.00		18.00	
Zn (ug/L)	98.0	129.0	1331.0	170.0	200.0	60.0

* Center for Watershed Protection 2003 (data compiled from National Urban Runoff Program studies, USGS studies, and EPA NPDES Phase I studies); numbers are median values, except for Cd, which is a mean value)

**Barr, 1997 (for MD)

Table 8. Average concentrations of the major pollutants in stormwater runoff measured in the Mully Grub study area compared to values reported in the literature. Only pollutants for which comparisons could be found are recorded in this table.

DATE	(ppm) NO3	(ppm) NH3-N	(ppm) Reac P	(umhos) Cond	(ppm) Alk	pH	(ppm) Chloride	(ppm) BOD	#/100ml FC	(ppm) TSS	(ppm) TDS	(ppb) Cd	(ppb) Cr	(ppb) Cu	(ppm) Fe	(ppb) Pb	(ppb) Mn	(ppb) Ni	(ppm) Zn
3/9/98	0.167	0.434	0.052	65.8	32.5	6.00	5.1	2.2	9.0	35.0	78.9	0.37	3.76	5.63	0.465	19.30	38.69	0.82	0.074
4/10/98	0.733	1.215	0.052	107.5	50.0	6.85	4.4	7.0	710.7	1795.5	93.4	0.77	18.16	8.49	0.537	27.83	55.50	2.30	0.123

Table 9. Average concentrations of analytes at 6 stormwater sites sampled in the Mully Grub subwatershed during two stormwater runoff events.

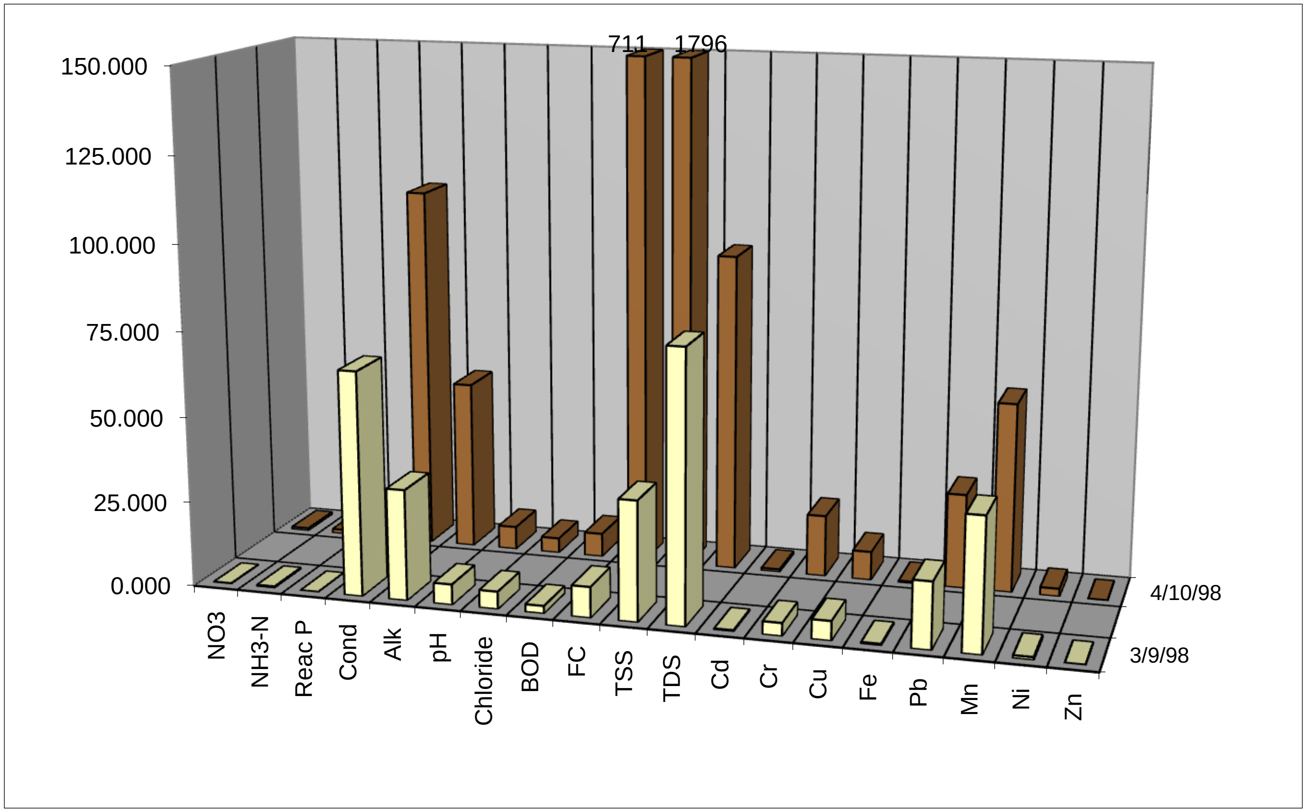


Figure 6. Graphical representation of average concentrations of analytes at 6 street sites sampled in the Mully Grub subwatershed during two stormwater runoff events.

DATE OF EVENT	TOTAL Z-SCORE	RAINFALL ON DATE (inches)	ANTECEDENT CONDITIONS RAINFALL PREVIOUS WEEK (inches)	SNOW PREVIOUS WEEK (inches)	RAINFALL PREVIOUS MONTH (inches)	SNOW PREVIOUS MONTH (inches)
2/28/1995	-2.58	0.55	0.09	0.00	1.15	6.50
3/8/1995	8.74	0.52/sm	0.32	0.00	1.51	*1.00
4/12/1995	-18.44	0.71	1.06	0.00	1.28	0.00
2/20/1996	17.48	1.01/sm	0.10	0.00	3.27	7.00
3/5/1996	0.03	0.66	0.60	0.00	2.13	1.00
4/1/1996	-5.23	1.02	1.00	0.00	3.54	0.50
3/9/1998	+LESS DEGRADED	1.41	0.63	0.00	5.92	0.00
4/10/1998	+MORE DEGRADED	1.26	0.15	0.00	4.51	0.00

*2/4/95 = 5.5 " snow
sm=snowmelt event

+ z-scores could not be calculated for 1998 since only two events were sampled.

Table 10. List of runoff events with a summary of antecedent conditions and rainfall data for the dates sampled. Total z-scores are listed where possible.

Our data from 1995 and 1996 also suggest that the amount of snowfall during the previous month is positively correlated with the severity of the pollution event (r=0.910 and 0.988, respectively).[4] This can be explained by the phenomenon of accumulated pollutants in snow being released over a short period of time as the snow melts and produces runoff. Both of the most impacted runoff events in 1995 and 1996 were snowmelt events. These data corroborate other studies in the literature, which have demonstrated the high impact of snowmelt on the quality of stormwater runoff (Oberts 2000, Buttle and Xu 1988). This phenomenon of increased pollutants in snowmelt water runoff may also explain, in part, the lower concentrations of pollutants in the street sites studied in 1998 (which contained no snowmelt events), compared to those in other sections of the watershed in earlier studies.

The effects of stormwater runoff on water quality at instream sites in the Mully Grub and the Letort Spring Run

The previous section has documented the nature and the amount of pollutants that are coming off of the streets of Carlisle and into the Mully Grub during various storm events. Do those pollutants have an impact on the water quality of the Mully Grub and do they impact the Letort Spring Run, just below the confluence?

Effect of stormwater runoff on water quality in the Mully Grub

Water quality indicators were measured on samples taken from sites in the Mully Grub and Letort Spring Run both between and during storm events in 1998 and 1999 (Table 11). Table 12 and Figure 7 show the average values of water quality indicators in the Mully Grub during and between storms for 1998 and 1999. Although there is some variability in the data, there are some notable and persistent patterns.

During storms, higher concentrations of the pollutants associated with vehicular traffic and organic pollution are found in the Mully Grub. Indicators associated with organic materials include: ammonia-nitrogen, fecal coliform, BOD, and total suspended solids; those associated with vehicular traffic include all of the metals measured, that is, cadmium, chromium, copper, iron, lead, manganese, nickel, zinc, and aluminum. In fact, during storm events, most of the water in the Mully Grub consists of stormwater runoff accumulated from the streets of Carlisle and conveyed through the storm sewers to the Mully Grub.

During periods between storm samplings, when most of the water in the Mully Grub is from limestone, groundwater springs beneath the town of Carlisle (base flow), the Mully Grub shows higher concentrations of parameters that are typically high in the local groundwater. These include nitrate, conductivity, alkalinity, and hardness. These patterns clearly demonstrate that the Mully Grub is adversely impacted by the pollutants found in urban runoff during storm events, and then returns to a higher water quality typical of our limestone streams and groundwater, during base flow conditions.

[4] There was no snowfall in the months previous to the 1998 runoff events.

AVERAGE OF STORMWATER SAMPLINGS FOR INSTREAM SITES (3/9/98,4/10/98)

	NO3 (ppm)	NH3-N (ppm)	*Reac P (ppm)	Cond (umohs)	Alk (ppm)	pH	Hard (ppm)	Chloride (ppm)	BOD (ppm)	FC (#/100 ml)	Tot coli (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppm)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppm)	Al (ppb)
#1- MG - below Hanover St.	0.95	0.540	0.078	275	115	6.4	ND	28.4	9.8	999	ND	1616.7	70.0	0.10	2.30	4.73	0.290	11.85	16.99	0.42	0.050	ND
#2- MG- us fr Bedford St.	0.83	0.438	0.065	300	133	6.8	ND	17.5	8.1	963	ND	3.4	173.4	1.80	2.11	4.79	0.250	8.35	13.96	0.31	0.041	ND
#4- Letort, US	3.95	0.048	0.023	465	236	7.1	ND	8.1	2.7	393	ND	0.0	173.4	0.10	1.79	1.35	0.075	0.72	14.62	0.13	0.000	ND
#5- Letort, DS	0.83	0.515	0.128	305	133	6.5	ND	15.3	11.2	3146	ND	0.4	230.0	0.00	2.13	4.78	0.300	10.15	14.72	2.26	0.036	ND

BETWEEN STORM SAMPLING OF INSTREAM SITES (4/6/98)

	NO3 (ppm)	NH3-N (ppm)	*Reac P (ppm)	Cond (umohs)	Alk (ppm)	pH	Hard (ppm)	Chloride (ppm)	BOD (ppm)	FC (#/100 ml)	Tot coli (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppb)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppb)	Al (ppb)
#1- MG - below Hanover St.	2.35	0.000	0.010	700	230	6.7	ND	38.4	ND	35	ND	3.3	226.7	0.00	0.92	1.23	0.000	0.50	0.88	0.00	0.000	ND
#2- MG- us fr Bedford St.	1.70	0.000	0.030	750	255	6.7	ND	38.8	ND	66	ND	0.0	303.3	0.40	0.09	5.21	0.000	0.20	3.96	0.00	0.000	ND
#4- Letort, US	2.25	0.095	0.030	455	200	7.3	ND	10.6	ND	26	ND	10.0	156.7	0.10	1.23	1.52	0.000	0.20	1.98	0.00	0.000	ND
#5- Letort, DS	2.55	0.000	0.010	600	255	6.9	ND	23.4	ND	10	ND	6.7	976.7	0.00	0.70	1.44	0.000	0.40	3.70	0.00	0.000	ND

STORM SAMPLING OF INSTREAM SITES (2/28/99)

	NO3 (ppm)	NH3-N (ppm)	*Reac P (ppm)	Cond (umohs)	Alk (ppm)	pH	Hard (ppm)	Chloride (ppm)	BOD (ppm)	E.coli (#/100 ml)	Tot coli (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppb)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppb)	Al (ppb)
#1- MG - below Hanover St.	0.50	0.560	0.170	330	64	6.6	59	30.4	2.8	ND	ND	443.3	60.0	0.38	ND	7.09	284.0	10.25	30.05	3.27	68.0	170.2
#2- MG- us fr Bedford St.	0.60	0.550	0.200	368	76	6.5	80	33.0	2.4	ND	ND	483.3	70.0	0.33	ND	8.48	484.0	16.03	18.35	4.74	79.0	228.0
#3-MG - baseball fields	0.60	0.590	0.100	359	24	6.6	70	55.0	0.9	ND	ND	413.3	50.0	0.34	ND	7.99	490.0	18.20	13.19	2.44	75.0	264.4
#4-Letort, us	4.70	0.045	0.140	470	204	6.9	241	8.6	0.3	ND	ND	516.7	160.0	0.09	ND	1.67	202.0	1.38	16.81	0.54	19.0	121.5
#5-Letort, ds	1.60	0.595	0.290	390	70	7.1	77	69.6	2.1	ND	ND	473.3	116.7	0.33	ND	7.60	340.0	12.36	16.79	1.14	70.0	220.2

BETWEEN STORM SAMPLING OF INSTREAM SITES (3/22/99)

	NO3 (ppm)	NH3-N (ppm)	*Reac P (ppm)	Cond (umohs)	Alk (ppm)	pH	Hard (ppm)	Chloride (ppm)	BOD (ppm)	E. coli (#/100 ml)	Tot coli (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppb)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppb)	Al (ppb)
#1- MG - below Hanover St.	2.75	0.015	0.180	339	224	6.0	278	69.0	2.0	2.0	236.5	396.7	276.7	0.03	ND	4.49	80.0	1.50	ND	2.61	34.0	34.2
#2- MG- us fr Bedford St.	2.60	0.050	0.260	359	193	6.5	274	59.3	1.9	2.0	271.7	423.3	263.3	0.06	ND	2.20	116.0	3.02	ND	2.43	36.0	55.6
#3-MG - baseball fields	2.80	0.015	0.000	361	212	6.4	284	53.1	1.8	0.0	94.3	426.7	320.0	0.03	ND	3.83	86.0	2.07	ND	0.24	34.0	46.1
#4-Letort, us	4.40	0.085	0.100	459	209	7.4	272	16.0	1.7	35.6	142.5	426.7	213.3	0.00	ND	1.36	198.0	1.41	ND	0.30	15.0	91.9
#5-Letort, ds	2.45	0.060	0.030	680	231	7.1	276	30.0	1.6	0.0	185.0	436.7	323.3	0.06	ND	1.91	102.0	2.83	ND	0.82	31.0	86.6

Table 11. Concentrations of parameters measured in 1998 at 4 instream sites during two storm events and between storm events, and in 1999 at 5 instream sites during one storm event and between storm events.

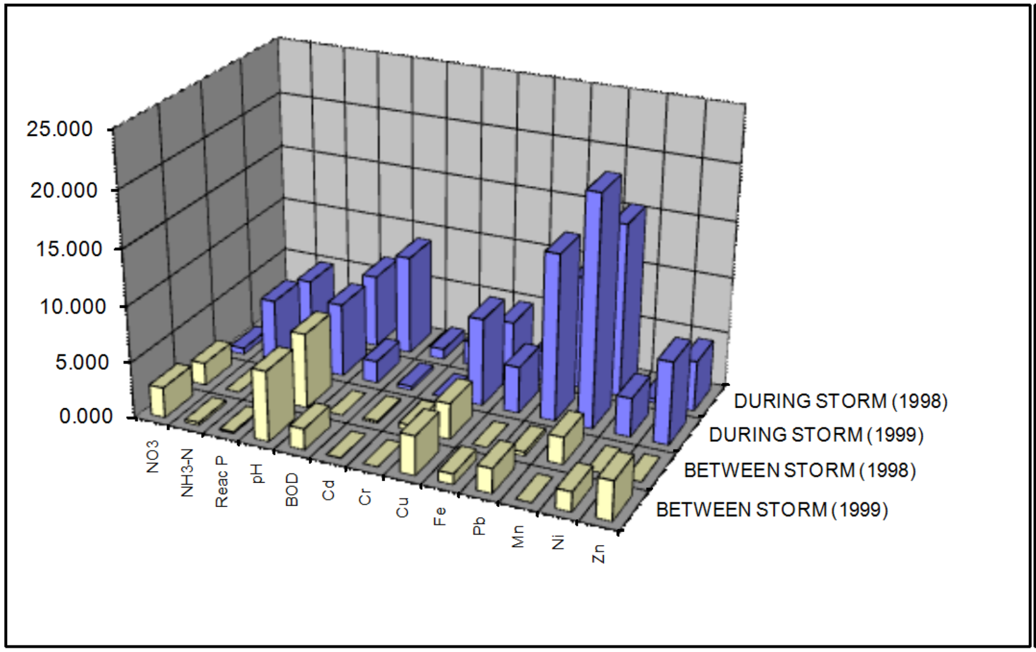
= violation of drinking w ater standard

= violation of instream w ater quality criteria

* Although there is no statew ide P standard, 0.100 mg/L is w idely accepted as a threshold level for impact.

	NO3 (ppm)	NH3-N (ppmx10)	Reac P (ppm)	Cond (umhos)	Alk (ppm)	pH	Hard	Chloride (ppm)	BOD (ppm)	FC (#/100 ml)	Total coli	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppb/100)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Al (ppb)	Zn (ppb/10)
DURING STORM (1998)	0.888	4.890	0.071	287.5	123.8	6.55	ND	22.9	8.9	981.0	ND	810.0	121.7	0.95	2.20	4.76	2.700	10.10	15.48	0.36	ND	4.5
DURING STORM (1999)	0.570	5.700	0.160	352.0	55.0	6.60	69.0	39.5	2.0	ND	ND	466.6	60.0	0.35	ND	7.85	4.190	14.83	20.53	3.48	220.9	7.4
BETWEEN STORM (1998)	2.025	0.000	0.020	725.0	242.5	6.70	ND	38.6	ND	50.5	ND	1.7	265.0	0.20	0.51	3.22	0.000	0.35	2.42	0.00	ND	0.0
BETWEEN STORM (1999)	2.720	0.270	0.147	353.0	210.0	6.30	279.0	60.5	1.9	1.3	200.8	415.6	286.7	0.04	ND	3.51	0.940	2.20	ND	1.76	45.3	3.5

Table 12. Average values of chemical indicators at instream Mully Grub sites, between and during storm events, 1998-1999.



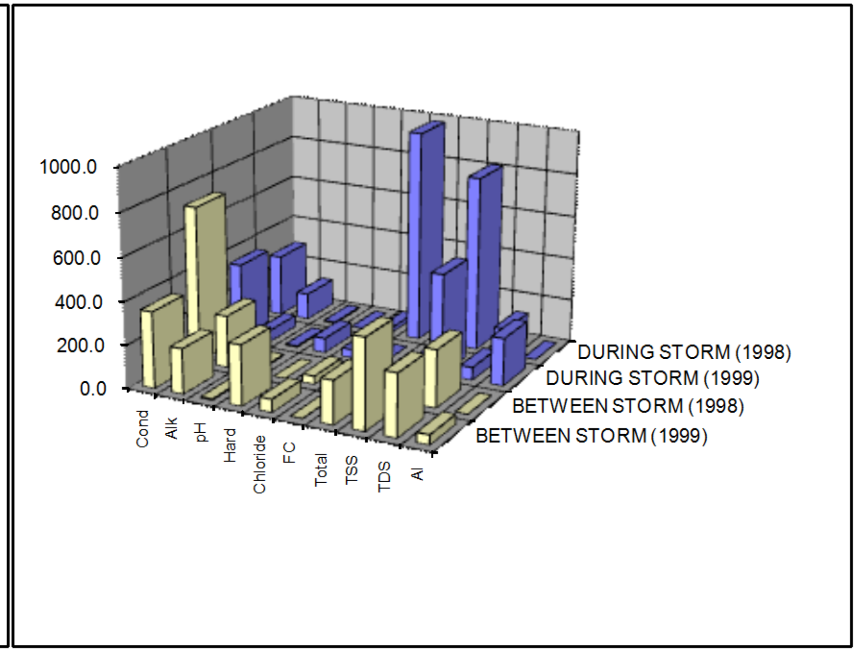


Figure 7. Graphical depiction of average values of chemical indicators at all Mully Grub instream sites, between and during storm events, 1998 and 1999. Data are in Table 12.

Effect of the Mully Grub on the Letort Spring Run, during runoff events

Comparing water quality in the Letort Spring Run upstream and downstream from the Mully Grub confluence during urban runoff events in both 1998 and 1999 demonstrates that the pollutants conveyed to the Mully Grub have an adverse impact on water quality in the Letort Spring Run. (Table 13, Figure 8 [1998] and Table 14, Figure 9 [1999]). Although the details of the impact vary from year to year, generally speaking, concentration of metals increase in the Letort Spring Run after the confluence with the Mully Grub, whereas concentrations of indicators associated with ground water, such as alkalinity, hardness, and conductivity decrease after the confluence. Pollutants associated with organic waste, such as BOD and fecal coliform, are higher in the Mully Grub during runoff events than in the upstream Letort, but are then even higher in the downstream Letort than in the Mully Grub. These elevated concentrations are probably attributable to the combined impact of the Mully Grub and a large population of geese and ducks that live just downstream from where the Mully Grub enters the Letort Spring Run.

These patterns clearly demonstrate that not only are pollutants in urban runoff having an impact on the Mully Grub, but that the Mully Grub is then conveying these pollutants into the Letort Spring Run. These pollutants are entering the Letort in the vicinity of the proposed handicapped anglers' access and fish habitat restoration project mentioned above.

Pollutants in the Mully Grub, in relation to water quality criteria

Table 15 shows PA DEP water quality criteria (Pennsylvania Code 2004a, Pennsylvania Code 2004b) and drinking water maximum contaminant levels (Pennsylvania Department of Environmental Protection 2002). Individual values of water samples from the Mully Grub and Letort Spring Run that exceeded water quality or drinking water criteria are shaded in Table 11. Violations of water and drinking water criteria include various sites for the following indicators: reactive phosphorus, pH, fecal coliform, total dissolved solids, lead, and aluminum.

Table 15 also lists average values for chemical indicators in the Mully Grub during storm events in 1998 and 1999. A comparison of these values to water and drinking water criteria also show violations for drinking water standards of aluminum, lead, iron, and fecal coliform. Violations of instream water quality criteria include ammonia-nitrogen, reactive phosphorus, and lead. Copper and zinc are close to maximum permissible levels in streams.

Water quality data collected on instream sites indicate that stormwater runoff is degrading water quality both in the Mully Grub and in the Letort Spring Run. Since the Letort Spring Run is an exceptional value stream just upstream from its confluence with the Mully Grub, any degradation of water quality should be mitigated, whether or not water quality criteria are exceeded. Pollution prevention should include consideration of

1998	NO3 (ppm)	NH3-N (ppmx10)	Reac P (ppmx10)	Cond (umohs)	Alk (ppm)	pH	Chloride (ppm)	BOD (ppm)	FC (#/100 ml)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cr (ppb)	Cu (ppb)	Fe (ppmx10)	Pb (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppb/10)
LETORT, US	3.950	0.480	0.230	465.0	236.0	7.05	8.1	2.67	393	0.0	173.4	0.10	1.79	1.35	0.750	0.72	14.62	0.13	0.000
MULLY GRUB	0.888	4.890	0.710	287.5	123.8	6.55	22.9	8.95	981	810.0	121.7	0.95	2.20	4.76	2.700	10.10	15.48	0.36	4.500
LETORT, DS	0.825	5.150	1.280	305.0	132.5	6.45	15.3	11.25	3146	0.4	230.0	0.00	2.13	4.78	3.000	10.15	14.72	2.26	3.600

Table 13. Values of parameters measured at 4 instream sites during 2 storm events in spring, 1998. The concentrations of parameters at the two Mully Grub sites have been averaged. Data have been used to evaluate the effect of the Mully Grub on the Letort Spring Run.

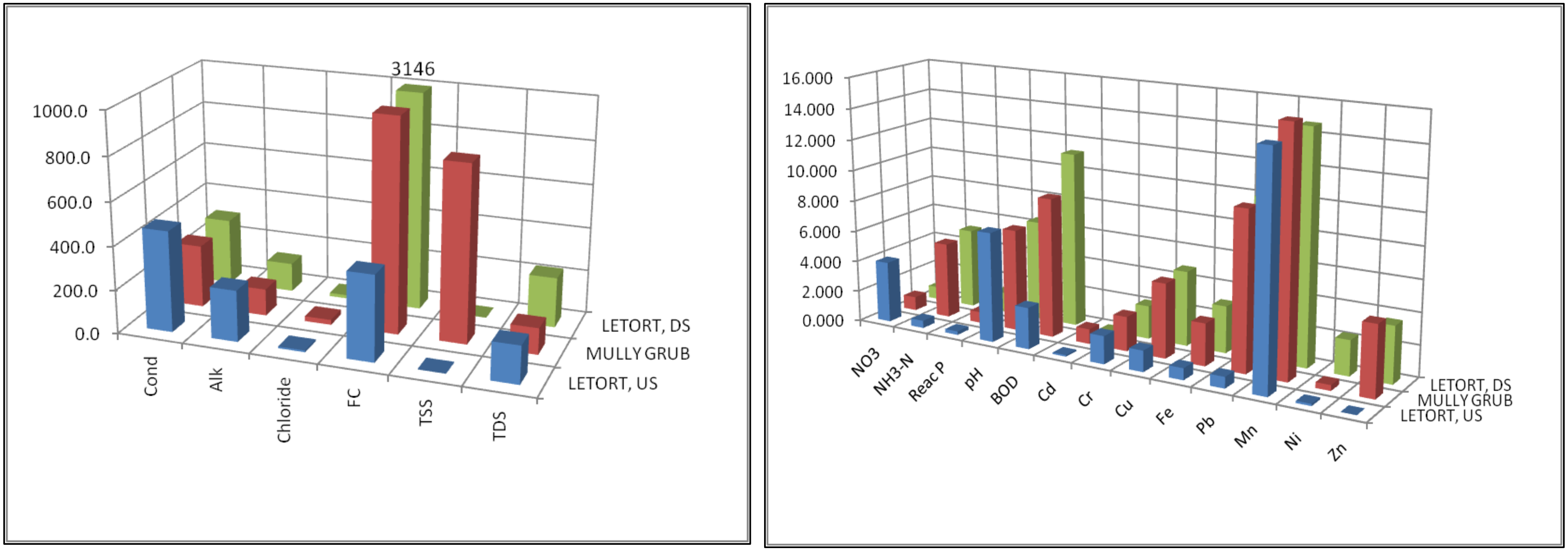
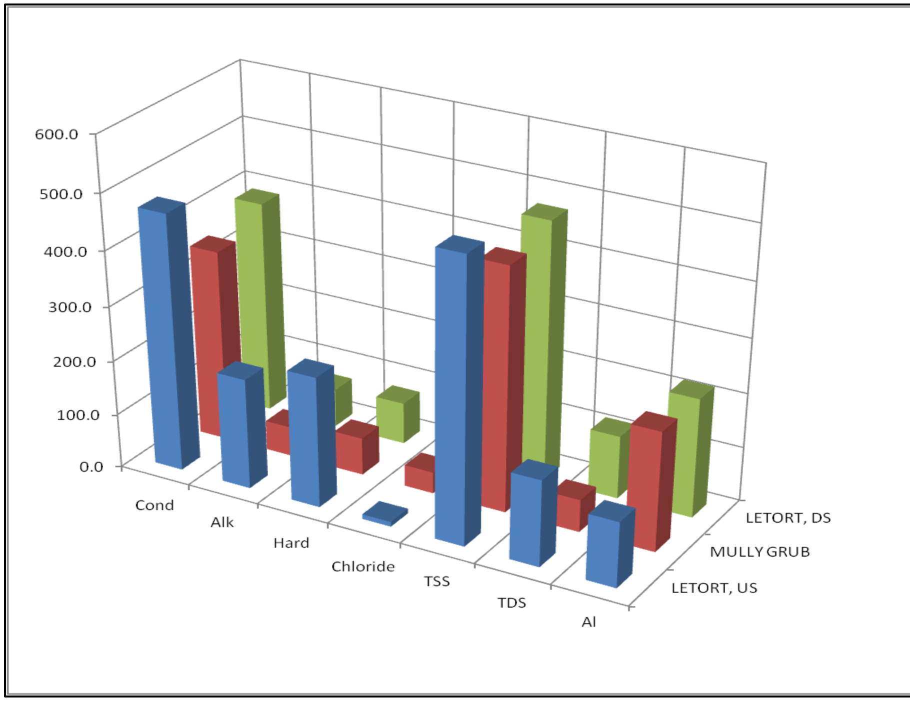


Figure 8. Graphical depiction of water quality values within the Mully Grub and upstream and downstream of the confluence in the Letort, during stormwater runoff events in spring, 1998. Data are in Table 13.

1999	NO3 (ppm)	NH3-N (ppmx10)	Reac P (ppmx10)	Cond (umohs)	Alk (ppm)	pH	Hard (ppm)	Chloride (ppm)	BOD (ppm)	TSS (ppm)	TDS (ppm)	Cd (ppb)	Cu (ppb)	Fe (ppmx10)	Pb (ppb)	Mn (ppb/10)	Ni (ppb)	Zn (ppb/10)	Al (ppb)
LETORT, US	4.700	0.450	1.400	470.0	204.0	6.9	241.0	8.6	0.30	516.7	160.0	0.09	1.67	2.020	1.38	1.68	0.54	1.9	121.5
MULLY GRUB	0.570	5.700	1.600	352.0	55.0	6.6	69.0	39.5	2.00	446.6	60.0	0.35	7.90	4.190	14.83	2.05	3.50	7.4	220.9
LETORT, DS	1.600	5.950	2.900	390.0	70.0	7.1	77.0	69.6	2.10	473.3	116.7	0.33	7.60	3.400	12.36	1.68	1.14	7.0	220.2

Table 14. Values of parameters measured at 5 instream sites during a storm event in spring, 1999. The concentrations of parameters at the three Mully Grub sites have been averaged. Data have been used to evaluate the effect of the Mully Grub on the Letort Spring Run.



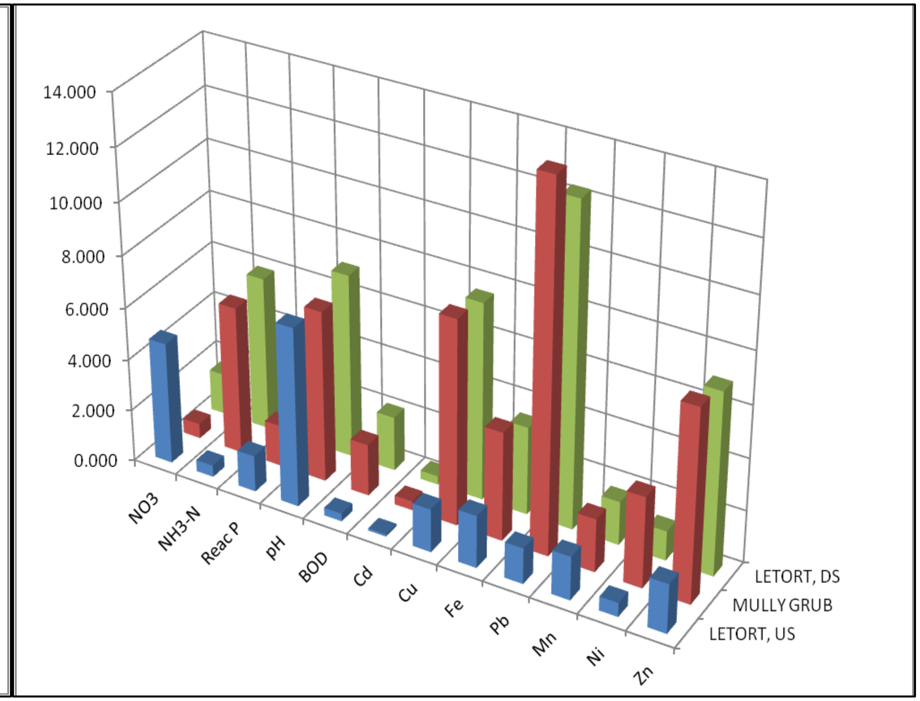


Figure 9. Graphical depiction of water quality values within the Mully Grub and upstream and downstream of the confluence in the Letort, during a stormwater runoff event (2/28/99). Data are in Table 14.

Chemical indicator	Average conc Mully Grub 1998	Average conc Mully Grub 1999	Water quality criteria (PA DEP 11/03) Chronic	Acute	Drinking Water MCLs (PA DEP 11/03)
Al (ug/L) +		220.9			200 ug/L (2°)
Alkalinity (mg/L)	123.8	55.0		>20 mg/L	
Cd (ug/L) +	0.95	0.35	2.2 ug/L	4.3 ug/L	5 ug/L
Cr (ug/L)*	2.20				100 ug/L
Cu (ug/L) +	4.76	7.85	9 ug/L	13 ug/L	1000 ug/L
Cl (mg/L)	22.9	39.5		<250 mg/L	250 mg/L (2°)
Fe (mg/L)	0.270	0.419		<1.5 mg/L(total)	0.3 mg/L (2°)
Fecal Coliform (#/100 ml)	981			May-Sept: <200/100 ml; Oct-April: <2000/100 ml	0/100 ml
Mn (ug/L)	15.48	20.53		< 1000 ug/L (total)	50 ug/L (2°)
NH3-N (mg/L) ++	4.89	5.700	2.2 mg/L	8.3 mg/L	
Ni (ug/L) +	0.36	3.48	52 ug/L	470 ug/L	
NO3-N (mg/L)	0.89	0.57		<10mg/L	10 mg/L
P (Reactive) (mg/L)**	0.07	0.16		>0.1 mg/L (guideline)	
Pb (ug/L) +	10.1	14.8	2.5 ug/L	65 ug/L	5 ug/L
pH	6.6	6.6		6.0-9.0	6.5-8.5 (2°)
Total Dissolved Solids (mg/L)	122	60	<500 mg/L	<750 mg/L	500 mg/L (2°)
Zn ug/L	45.00	74.00	120 ug/L	120 ug/L	5000 ug/L (2°)

++ Temp and pH dependent; used T=13.4°C and pH=7.6 (July-Sept median estimates for the Letort)

+ Hardness Dependent Criteria (100.0 mg/L used)

* PA DEP manages aquatic resources for chromium III and chromium VI separately; total chromium was measured in this study.

** Although there is no statewide P standard, 0.100 mg/L is widely accepted as a threshold level for impact.

(2°) = secondary maxiumum contaminant level, indicating that the pollutant is not controlled as a health risk, but rather for taste or aesthetics.

MCL - maximum contaminant levels allowed

= violation of instream water quality criteria

= violation of drinking water standard

Table 15. Average concentrations of the major pollutants in the Mully Grub, during stormwater events, compared to DEP water quality and drinking water criteria. Only analytes for which criteria could be found are listed here.

strategies to prevent generation of the pollutants, as well as strategies to prevent the pollutants from traveling into the Mully Grub and to the Letort Spring Run.

Effect of stormwater runoff on sediments in the Mully Grub and the Letort Spring Run

Since certain analytes accumulate in the bottom sediments of streams over time, analysis of sediment composition is often an excellent way to assess cumulative impact on an aquatic system. In contrast to water column chemistry, which is just a snapshot of the condition of the stream at a moment, sediment chemistry is an integrative water quality indicator. In addition, toxicants within sediments can have a direct adverse effect on benthic organisms (Adams et al. 1992, Schlekat et al. 1994).

Table 16 and Figure 10 show the results of the analysis of 9 metals and total petroleum hydrocarbons from 3 sites within the Mully Grub, from one site in the Letort Spring Run upstream from the confluence, and from one site in the Letort Spring Run downstream from the confluence. These data indicate 7 of the 10 analytes show their highest concentrations at the most upstream Mully Grub site, that is, the Hanover St. outfall. This is the site where the Mully Grub emerges from its underground journey, during which it flows through storm drains and receives both ground water and stormwater runoff from the streets of Carlisle. The analytes whose concentrations are highest at the Hanover St. outfall include: cadmium, chromium, copper, nickel, lead, zinc and total petroleum hydrocarbons. The positioning of these high concentrations at the first site below the outfall clearly implicates stormwater runoff as the primary contaminant source.

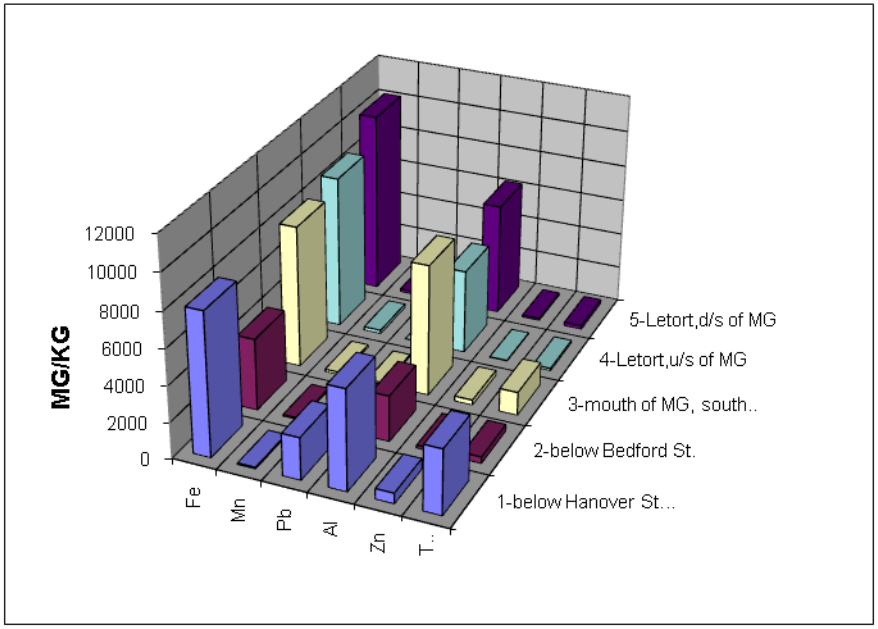
These same 7 analytes show elevated concentrations in the Letort sediments after the confluence of the Mully Grub in comparison to the site upstream from the confluence, demonstrating a clear impact of the Mully Grub as it conveys stormwater runoff to the Letort Spring Run (Table 16, Figure 10).

Data from sediments in other sections of the Letort Spring Run (Wilderman et al, 1994, 1997) are shown in Table 17, along with sediment quality guidelines (SQGs) (Ingersoll et al. 2000, Ingersoll et al. 2001, Efroymson et al. 1997). The SQGs used in the table include consensus-based threshold effect concentrations (TEC), which are concentrations below which adverse effects are not expected to occur, and probable effect concentrations (PEC), which are concentrations above which adverse effects are expected to occur frequently. Sediments with concentrations below the TEC for a given analyte are considered non-polluted, those between the TEC and PEC for that analyte are considered moderately polluted, and those above the PEC for that analyte are considered heavily polluted. All data in Table 17 are color-coded based on the pollution category into which the sediment samples fall for any given chemical analyte.

These data show that the average concentrations of total petroleum hydrocarbons, lead and zinc are considerably higher in the Mully Grub sediments than in any other section of the Letort Spring Run (Figure 11). Lead falls into the heavily polluted

Site Number/Description	Fe	Mn	Pb	Al	Zn	Cu	Ni	Cr	Cd	TPH
1-below Hanover St. outfall	7983.0	86.8	2351.0	5570.0	582.0	50.8	16.5	28.4	4.5	3600.0
2-below Bedford St.	4010.0	91.7	66.4	2553.0	160.0	14.8	8.1	14.7	1.1	360.0
3-mouth of MG, south side	7950.0	136.0	100.0	7305.0	280.0	27.9	14.1	26.4	1.4	1300.0
4-Letort,u/s of MG	8570.0	200.0	13.7	4697.0	36.8	7.3	9.9	18.0	1.1	130.0
5-Letort,d/s of MG	10155.0	169.0	53.5	6274.0	112.0	16.2	11.6	22.0	1.4	210.0

Table 16. Results of analysis of metals and total petroleum hydrocarbons from bottom sediments in the Mully Grub above and below its confluence with the Letort. All concentrations are mg/kg.



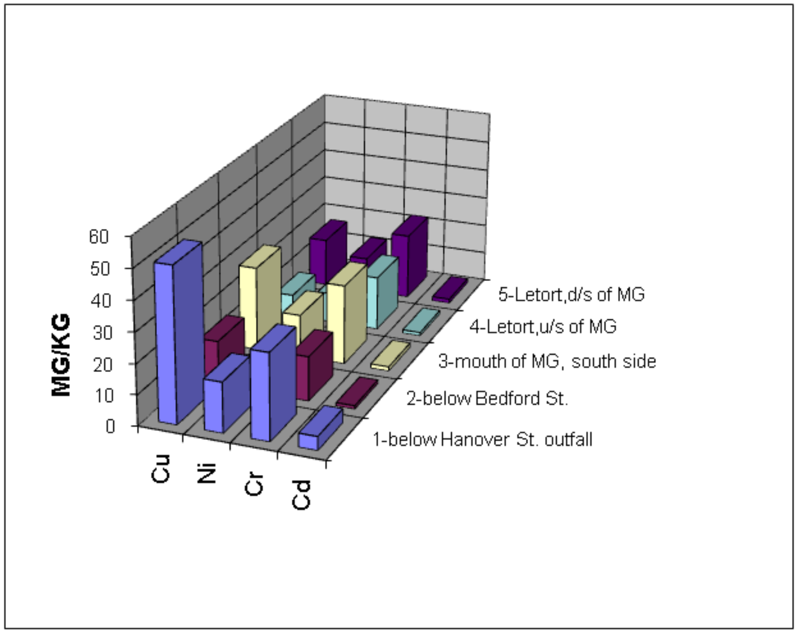


Figure 10. Graphical depiction of concentrations of metals and total petroleum hydrocarbons in sediments in the study area. Data are in Table 16.

References	RESULTS OF SEDIMENT ANALYSIS 1993-98				SEDIMENT CRITERIA Ingersoll et al. 2001	Ingersoll et al. 2001
	Upstream average (mg/kg DW)	MG average (mg/kg DW)	Urban average (mg/kg DW)	Trucking average (mg/kg DW)	Consensus-based TEC (mg/kg DW)	Consensus-based PEC (mg/kg DW)
	N= 8	N= 3	N= 10	N= 12		
Aluminum	9527.5	5142.7	6807.0	6608.0	ND	ND
Cadmium	2.50	2.33	2.10	2.27	0.99	4.98
Chromium	30.95	23.17	27.40	29.83	43.40	111.00
Copper	17.99	31.17	23.68	46.14	31.60	149.00
Iron	16525.0	6647.7	12710.0	13280.0	ND	ND
Lead	29.05	839.13	84.77	75.00	35.80	128.00
Manganese	195.75	104.83	*478.9	213.60	ND	ND
Nickel	15.28	12.90	15.03	11.09	22.70	48.60
Zinc	56.24	340.67	141.84	141.26	121.00	459.00
PHC	ND	1753.33	544.00	1112.50	ND	ND

xxx	= below TEC; unpolluted
xxx	= above TEC; moderately polluted
xxx	= above PEC; heavily polluted
xxx	= no criteria established

* This average concentration is elevated by the presence of one very highly concentrated sample at the High St. sewer outfall (Mn concentration = 3010 ppm). The average concentration of Mn in the urban reach sediments excluding this sample is 197.7 ppm.

Table 17. Comparison of results of sediment analyses in the present study with analyses of Letort sediments in previous studies (Wilderman et al. 1994,1997). Sediment criteria are listed and data are color-coded, based on criteria exceeded.

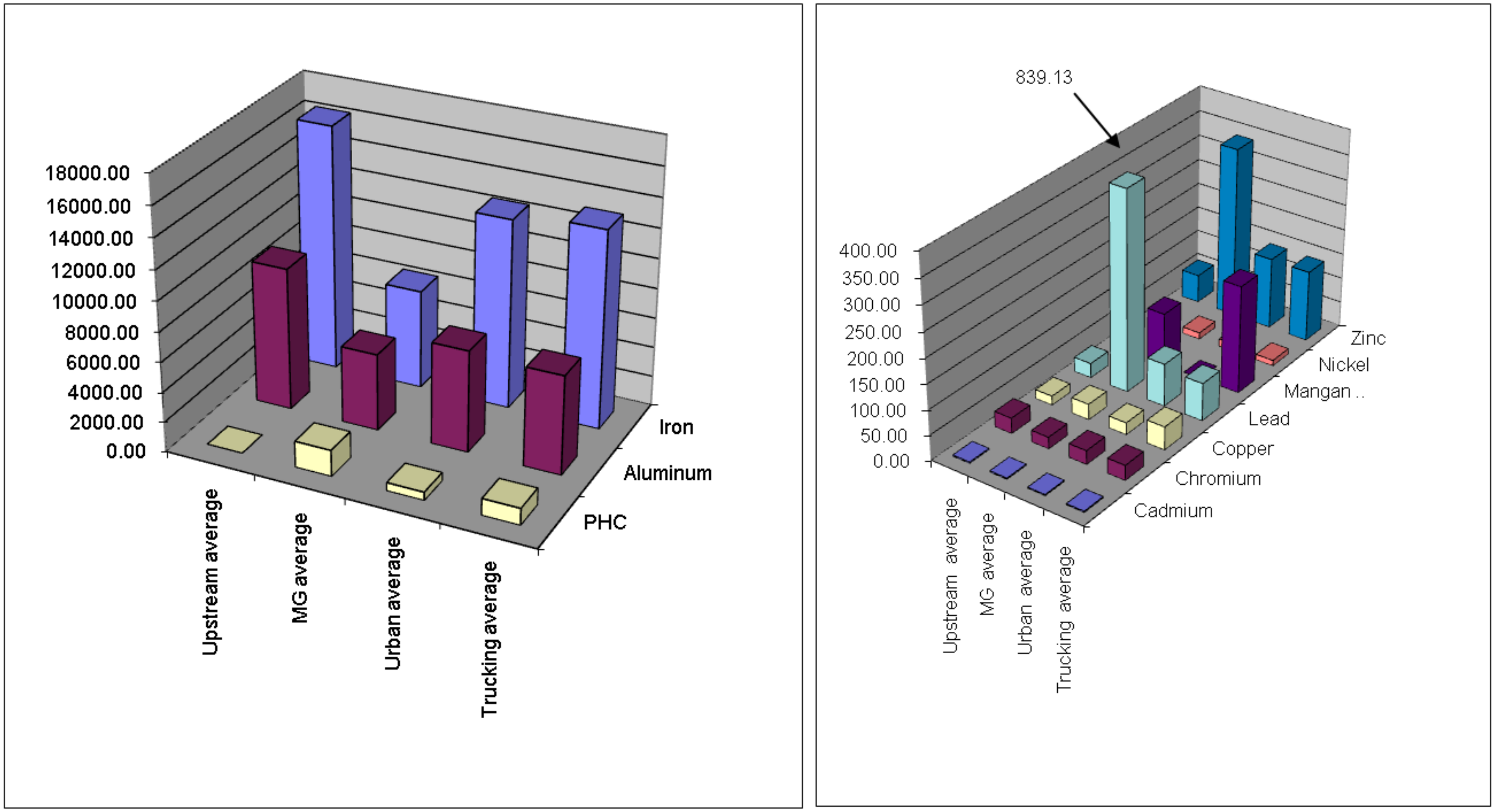


Figure 11. Graphical depiction of concentraion of metals and PHC in sediments in the Letort Spring Run. Data are in Table 17.

category for sediments in the Mully Grub and represents the worst contaminants in the sediments. Both zinc and copper are elevated in the Mully Grub in comparison to other sections of the Letort and fall into the moderately polluted classification for sediments (Table 17). Zinc concentrations are almost 3x higher in the Mully Grub than other sections of the Letort; copper concentrations in the Mully Grub are not as high as they are in the trucking reach of Middlesex Township (Table 17). Since estimates show that 50% of copper in stormwater runoff comes from vehicle brake pad linings wear (Center for Watershed Protection 2003), it is reasonable to expect that an area with a great deal of trucking activity, such as Middlesex Township, would have high concentrations of copper accumulating in the sediments of receiving streams.

All reaches along the Letort that were sampled for sediments show average cadmium concentrations falling into the moderately polluted category, with little differences between stream reaches. The concentrations of the two other analytes for which there are SQGs (chromium and nickel) fall below the TEC in all reaches, indicating a non-polluted status (Table 17).

Iron and aluminum are actually highest in the upstream reach of the Letort, and lowest in the Mully Grub (Figure 11). These analytes may be largely derived from natural sources, including groundwater, and may also be byproducts of agricultural activity found in the upstream section. Manganese is fairly constant throughout the watershed, with the exception of a single sample in the urban section that is at an outfall which drains an old steel factory on-site landfill (Wilderman et al. 1994).

Sediment samples were analyzed for pesticides throughout the watershed in 1993, 1995, 1996 and 1998. Tables 18 and 19 list the pesticides found in Letort Spring Run and Mully Grub sediment samples, listed by compound and by site, respectively. Table 18 also includes SQGs for those analytes that have them (Ingersoll et al. 2001). Concentrations that exceed either the TEC or the PEC are color-coded into pollutional categories, as with the metals in Table 17. For every compound for which there is a sediment quality guideline, most of the samples in the Letort and/or the Mully Grub exceed that guideline. This clearly shows the concentrations of these pesticides are of concern.

Table 19 lists the compounds by site and therefore depicts spatial patterns. It can easily be seen from the table that the number of pesticides found in the Mully Grub are comparable to the numbers found at the major urban outfalls, with the numbers of compounds decreasing within the Mully Grub as we move from the Hanover St. outfall to the mouth of the Mully Grub. Along the Mully Grub itself, for any pesticides that show up in the sediment samples at more than one site (gamma-Chlordane, endrin, and 4,4'DDT), the highest concentrations are found in the most upstream site, below the Hanover St. outfall where the Mully Grub emerges from its underground journey through storm drains. These data demonstrate clearly that the source of the pesticides is the stormwater runoff and that the Mully Grub is comparable in delivery of pesticides to the other major urban outfalls downstream in the Letort.

CAS NO.	Pesticide compound	Sites where reported	Year	Concentration (ppb)	Sample quantitation limit (ppb)	Drinking MCL (ppb)	Consensus based TEC (ppb)	Consensus based PEC (ppb)
309-00-2	Aldrin	4- TU -- VINCE'S MEADOW	1993	90.00	5.00			
309-00-2	Aldrin	9- JUST BELOW MCKNIGHT ST OUTFALL	1993	25.00				
319-84-3	alpha-BHC	5- JUST NORTH OF BORO PUBLIC WORKS BLDG	1993	9.00	5.00			
319-84-6	beta-BHC	4- TU -- VINCE'S MEADOW	1993	14.00	5.00			
58-89-9	gamma-BHC (Lindane)	4- JUST BELOW MCKNIGHT ST OUTFALL	1996	3.25	5.00		2.37	4.99
5103-71-9	alpha-Chlordane	7- JUST BELOW HIGH ST. SEWER OUTFALL	1993	5.00	5.00	2.00	3.24	17.60
5103-71-9	alpha-Chlordane	8- HALFWAY DOWN BIDDLE MISSION PARK	1993	3.00			(total chlordane)	
5103-71-9	alpha-Chlordane	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	13.60				
5103-74-2	gamma-Chlordane	7- JUST BELOW HIGH ST. SEWER OUTFALL	1993	4.60	5.00	2.00		
5103-74-2	gamma-Chlordane	9- JUST BELOW MCKNIGHT ST OUTFALL	1993	11.00				
5103-74-2	gamma-Chlordane	10- JUST BELOW MEDIA OUTFALL	1993	24.00				
5103-74-2	**gamma-Chlordane**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**48.00**				
5103-74-2	**gamma-Chlordane**	**2-MULLY GRUB, BELOW BEDFORD ST.**	**1998**	**4.10**				
5103-74-2	**gamma-Chlordane**	**3-MOUTH OF MULLY GRUB**	**1998**	**11.00**				
2675-77-6	chlorneb	8- IN ALL AMERICAN RETENTION POND	1996	75.80	100.00			
21725-46-2	cyanazine	9- JUST BELOW MCKNIGHT ST OUTFALL	1993	620.00	500.00			
21725-46-2	cyanazine	10- JUST BELOW MEDIA OUTFALL	1993	499.00				
72-54-8	**4,4' DDD**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**31.00**	**10.00**		4.88	28.00
72-55-9	4,4' DDE	10- JUST BELOW MEDIA OUTFALL	1993	14.00	10.00		3.16	31.30
72-55-9	4,4' DDE	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	45.80				
72-55-9	**4,4' DDE**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**87.00**				
72-54-8	4,4' DDT	10- JUST BELOW MEDIA OUTFALL	1993	20.00	10.00		4.16	62.90
72-54-8	4,4' DDT	5- JUST BELOW MEDIA OUTFALL	1996	15.60				
72-54-8	4,4' DDT	4-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1995	17.00				
72-54-8	4,4' DDT	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	42.40				
72-54-8	4,4' DDT	7-UPSTREAM FROM MOUTH OF TP TRIB	1996	20.80				
72-54-8	4,4' DDT	10- 200 M. DOWNSTREAM FROM RT. 11 OVERPASS	1995	29.00				
72-54-8	**4,4' DDT**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**50.00**				
72-54-8	**4,4' DDT**	**3-MOUTH OF MULLY GRUB**	**1998**	**9.80**				
72-54-8	**4,4' DDT**	**5-DOWNSTREAM OF MULLY GRUB CONFLUENCE**	**1998**	**3.80**				
60-57-1	Dieldrin	4- JUST BELOW MCKNIGHT ST OUTFALL	1996	24.20	10.00		3.24	17.60
959-98-8	Endosulfan I	8- HALFWAY DOWN BIDDLE MISSION PARK	1993	3.00	5.00			
959-98-8	Endosulfan I	9- JUST BELOW MCKNIGHT ST OUTFALL	1993	32.00				
959-98-8	Endosulfan I	10- JUST BELOW MEDIA OUTFALL	1993	14.00				
33213-65-9	Endosulfan II	10- JUST BELOW MEDIA OUTFALL	1993	4.95	10.00			
1031-07-8	Endosulfan sulfate	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	28.20	10.00			
1031-07-8	**Endosulfan sulfate**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**290.00**				
1031-07-8	**Endosulfan sulfate**	**5-DOWNSTREAM OF MULLY GRUB CONFLUENCE**	**1998**	**36.00**				

Table 18. Pesticides found in Letort Spring Run sediment samples, listed by compound. Red numbers indicate moderate pollution; blue indicate heavy pollution. For site locations in the Letort Spring Run, see Wilderman 1994 and 1997. (Table continues on next page)

72-20-8	Endrin	10- JUST BELOW MEDIA OUTFALL	1993	15.00	10.00	2.00	2.22	207.00
72-20-8	Endrin	5- JUST BELOW MEDIA OUTFALL	1996	17.90				
72-20-8	Endrin	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	44.80				
72-20-8	**Endrin**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**120.00**				
72-20-8	**Endrin**	**2-MULLY GRUB, BELOW BEDFORD ST.**	**1998**	**15.00**				
72-20-8	**Endrin**	**3-MOUTH OF MULLY GRUB**	**1998**	**36.00**				
7421-39-4	Endrin aldehyde	4- JUST BELOW MCKNIGHT ST OUTFALL	1996	47.80	10.00			
7421-39-4	Endrin aldehyde	5- JUST BELOW MEDIA OUTFALL	1996	60.90				
7421-39-4	Endrin aldehyde	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	149.00				
7421-39-4	Endrin aldehyde	7-UPSTREAM FROM MOUTH OF TP TRIB	1996	41.30				
7421-39-4	Endrin aldehyde	8- IN ALL AMERICAN RETENTION POND	1996	11.60				
7421-39-4	Endrin aldehyde	10 - FROM RT. 11 OUTFALL PIPE NEAR IRON KETTLE	1996	31.80				
53494-70-5	**Endrine ketone**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**240.00**	**10.00**			
76-44-8	Heptachlor	9- JUST BELOW MCKNIGHT ST OUTFALL	1993	8.80	5.00	0.40		
76-44-8	Heptachlor	4-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1995	14.00				
76-44-8	**Heptachlor**	**4-UPSTREAM OF MULY GRUB CONFLUENCE**	**1998**	**14.00**				
76-44-8	**Heptachlor**	**2-MULLY GRUB, BELOW BEDFORD ST.**	**1998**	**6.40**				
1024-57-3	Heptachlor epoxide	4- JUST BELOW MCKNIGHT ST OUTFALL	1996	1.67	5.00	0.20	2.47	16.00
1024-57-3	Heptachlor epoxide	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	5.99				
1024-57-3	Heptachlor epoxide	9- WITHIN OIL BOOM AT RT. 11 OUTFALL	1996	2.86				
118-74-1	**Hexachlorobenzene**	**1-MULLY GRUB, BELOW HANOVER ST. OUTFALL**	**1998**	**300.00**	**100.00**	**1.00**		
72-43-5	Methoxychlor	2- JUST BELOW HIGH ST. SEWER OUTFALL	1996	46.20	50.00	40.00		
72-43-5	Methoxychlor	4- JUST BELOW MCKNIGHT ST OUTFALL	1996	47.90				
72-43-5	Methoxychlor	10- JUST BELOW MEDIA OUTFALL	1993	53.00				
72-43-5	Methoxychlor	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	182.00				
51218-45-5	metolachlor	2- 30 M. DOWNSTREAM FROM QUARRY OUTFALL	1995	220.00	250.00			
51218-45-5	metolachlor	8- HALFWAY DOWN BIDDLE MISSION PARK	1993	235.00				
51218-45-5	metolachlor	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	337.00				
51218-45-5	metolachlor	9- WITHIN OIL BOOM AT RT. 11 OUTFALL	1996	225.00				
54774-45-7	c-permethrin	6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1996	431.00	100.00			
54774-45-7	c-permethrin	10 - FROM RT. 11 OUTFALL PIPE NEAR IRON KETTLE	1996	76.60				
1918-16-7	propachlor	1- 30 M. UPSTREAM FROM BONNYBROOK RD.	1995	3700.00	100.00			
1918-16-7	propachlor	2- JUST BELOW HIGH ST. SEWER OUTFALL	1996	102.00				
1918-16-7	propachlor	5- MOUTH OF TP TRIB	1995	3900.00				
1918-16-7	propachlor	6- IN ALL AMERICAN RETENTION POND	1995	2300.00				
1918-16-7	propachlor	7- AT UPPER BOUNDARY OF SUNDAY FARM	1995	4200.00				
1918-16-7	propachlor	9- WITHIN OIL BOOM AT RT. 11 OUTFALL	1996	52.80				
1582-09-8	trifluralin	3- JUST UPSTREAM FROM 81 BRIDGE	1995	24.00	25.00			

xxx	= below TEC; unpolluted
xxx	= above TEC; moderately polluted
xxx	= above PEC; heavily polluted
xxx	= no criteria established

Table 18. Pesticides found in Letort Spring Run sediment samples, listed by compound. Red numbers indicate moderate pollution; blue indicate heavy pollution. For site locations in the Letort Spring Run, see Wilderman 1994 and 1997.

Sites where reported	CAS NO.	Pesticide compound	Year	Concentration (ppb)	Sample quantitation limit (ppb)
UPSTREAM REACH					
1- 30 M. UPSTREAM FROM BONNYBROOK RD.	1918-16-7	propachlor	1995	3700.00	0.1000
2- 30 M. DOWNSTREAM FROM QUARRY OUTFALL	51218-45-5	metolachlor	1995	220.00	0.2500
4- TU -- VINCE'S MEADOW	309-00-2	Aldrin	1993	90.00	0.0050
4- TU -- VINCE'S MEADOW	319-84-6	beta-BHC	1993	14.00	0.0050
5- JUST NORTH OF BORO PUBLIC WORKS BLDG	319-84-3	alpha-BHC	1993	9.00	0.0050
3- JUST UPSTREAM FROM 81 BRIDGE	1582-09-8	trifluralin	1995	24.00	0.0250
4-UPSTREAM OF MULY GRUB CONFLUENCE	76-44-8	heptachlor	1998	14.00	0.0050
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	5103-74-2	gamma-chlordane	1998	48.00	0.0050
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	72-20-8	endrin	1998	120.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	1031-07-8	endosulfan sulfate	1998	290.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	72-54-8	4,4' DDT	1998	50.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	72-54-8	4,4' DDD	1998	31.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	72-55-9	4,4' DDE	1998	87.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	53494-70-5	endrine ketone	1998	240.00	0.0100
1-MULLY GRUB, BELOW HANOVER ST. OUTFALL	118-74-1	hexachlorobenzene	1998	300.00	0.1000
2-MULLY GRUB, BELOW BEDFORD ST.	5103-74-2	gamma-Chlordane	1998	4.10	0.0050
2-MULLY GRUB, BELOW BEDFORD ST.	72-20-8	endrin	1998	15.00	0.0100
2-MULLY GRUB, BELOW BEDFORD ST.	76-44-8	heptachlor	1998	6.40	0.0050
3-MOUTH OF MULLY GRUB	5103-74-2	gamma-Chlordane	1998	11.00	0.0050
3-MOUTH OF MULLY GRUB	72-20-8	endrin	1998	36.00	0.0100
3-MOUTH OF MULLY GRUB	72-54-8	4,4' DDT	1998	9.80	0.0100
URBAN REACH					
5-DOWNSTREAM OF MULLY GRUB CONFLUENCE	1031-07-8	endosulfan sulfate	1998	36.00	0.0100
5-DOWNSTREAM OF MULLY GRUB CONFLUENCE	72-54-8	4,4'DDT	1998	3.80	0.0100
7- JUST BELOW HIGH ST. SEWER OUTFALL	5103-71-9	alpha-Chlordane	1993	5.00	0.0050
7- JUST BELOW HIGH ST. SEWER OUTFALL	5103-74-2	gamma-Chlordane	1993	4.60	0.0050
2- JUST BELOW HIGH ST. SEWER OUTFALL	72-43-5	Methoxychlor	1996	46.20	0.0500
2- JUST BELOW HIGH ST. SEWER OUTFALL	1918-16-7	propachlor	1996	102.00	0.1000
8- HALFWAY DOWN BIDDLE MISSION PARK	5103-71-9	alpha-Chlordane	1993	3.00	0.0050
8- HALFWAY DOWN BIDDLE MISSION PARK	959-98-8	Endosulfan I	1993	3.00	0.0050
8- HALFWAY DOWN BIDDLE MISSION PARK	51218-45-5	metolachlor	1993	235.00	0.2500

xxx	= below TEC; unpolluted
xxx	= above TEC; moderately polluted
xxx	= above PEC; heavily polluted
xxx	= no criteria established

Table 19. Pesticides found in Letort Spring Run sediment samples, listed by site and color-coded according to pollution category established in Table 17. (Table continues on next page)

9- JUST BELOW MCKNIGHT ST OUTFALL	309-00-2	Aldrin	1993	25.00	0.0050
4- JUST BELOW MCKNIGHT ST OUTFALL	58-89-9	gamma-BHC (Lindane)	1996	3.25	0.0050
9- JUST BELOW MCKNIGHT ST OUTFALL	5103-74-2	gamma-Chlordane	1993	11.00	0.0050
9- JUST BELOW MCKNIGHT ST OUTFALL	21725-46-2	cyanazine	1993	620.00	0.5000
4- JUST BELOW MCKNIGHT ST OUTFALL	60-57-1	Dieldrin	1996	24.20	0.0100
9- JUST BELOW MCKNIGHT ST OUTFALL	959-98-8	Endosulfan I	1993	32.00	0.0050
4- JUST BELOW MCKNIGHT ST OUTFALL	7421-39-4	Endrin aldehyde	1996	47.80	0.0100
9- JUST BELOW MCKNIGHT ST OUTFALL	76-44-8	Heptachlor	1993	8.80	0.0050
4- JUST BELOW MCKNIGHT ST OUTFALL	1024-57-3	Heptachlor epoxide	1996	1.67	0.0050
4- JUST BELOW MCKNIGHT ST OUTFALL	72-43-5	Methoxychlor	1996	47.90	0.0500
10- JUST BELOW MEDIA OUTFALL	5103-74-2	gamma-Chlordane	1993	24.00	0.0050
10- JUST BELOW MEDIA OUTFALL	21725-46-2	cyanazine	1993	499.00	0.5000
10- JUST BELOW MEDIA OUTFALL	72-55-9	4,4' DDE	1993	14.00	0.0100
10- JUST BELOW MEDIA OUTFALL	72-54-8	4,4' DDT	1993	20.00	0.0100
5- JUST BELOW MEDIA OUTFALL	72-54-8	4,4' DDT	1996	15.60	0.0100
10- JUST BELOW MEDIA OUTFALL	959-98-8	Endosulfan I	1993	14.00	0.0050
10- JUST BELOW MEDIA OUTFALL	33213-65-9	Endosulfan II	1993	4.95	0.0100
10- JUST BELOW MEDIA OUTFALL	72-20-8	Endrin	1993	15.00	0.0100
5- JUST BELOW MEDIA OUTFALL	72-20-8	Endrin	1996	17.90	0.0100
5- JUST BELOW MEDIA OUTFALL	7421-39-4	Endrin aldehyde	1996	60.90	0.0100
10- JUST BELOW MEDIA OUTFALL	72-43-5	Methoxychlor	1993	53.00	0.0500
TRUCKING REACH					
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	5103-71-9	alpha-Chlordane	1996	13.60	0.0050
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	72-55-9	4,4' DDE	1996	45.80	0.0100
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	72-54-8	4,4' DDT	1996	42.40	0.0100
4-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	72-54-8	4,4' DDT	1995	17.00	0.0100
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1031-07-8	Endosulfan sulfate	1996	28.20	0.0100
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	72-20-8	Endrin	1996	44.80	0.0100
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	7421-39-4	Endrin aldehyde	1996	149.00	0.0100
4-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	76-44-8	Heptachlor	1995	14.00	0.0050
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	1024-57-3	Heptachlor epoxide	1996	5.99	0.0050
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	72-43-5	Methoxychlor	1996	182.00	0.0500
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	51218-45-5	metolachlor	1996	337.00	0.2500
6-JUST DOWNSTREAM FROM SHADY LANE BRIDGE	54774-45-7	c-permethrin	1996	431.00	0.1000
7-UPSTREAM FROM MOUTH OF TP TRIB	72-54-8	4,4' DDT	1996	20.80	0.0100
7-UPSTREAM FROM MOUTH OF TP TRIB	7421-39-4	Endrin aldehyde	1996	41.30	0.0100
5- MOUTH OF TP TRIB	1918-16-7	propachlor	1995	3900.00	0.1000
8- IN ALL AMERICAN RETENTION POND	2675-77-6	chlorneb	1996	75.80	0.1000
8- IN ALL AMERICAN RETENTION POND	7421-39-4	Endrin aldehyde	1996	11.60	0.0100
6- IN ALL AMERICAN RETENTION POND	1918-16-7	propachlor	1995	2300.00	0.1000
7- AT UPPER BOUNDARY OF SUNDAY FARM	1918-16-7	propachlor	1995	4200.00	0.1000
9- WITHIN OIL BOOM AT RT. 11 OUTFALL	1024-57-3	Heptachlor epoxide	1996	2.86	0.0050
9- WITHIN OIL BOOM AT RT. 11 OUTFALL	51218-45-5	metolachlor	1996	225.00	0.2500
9- WITHIN OIL BOOM AT RT. 11 OUTFALL	1918-16-7	propachlor	1996	52.80	0.1000
10 - FROM RT. 11 OUTFALL PIPE NEAR IRON KETTLE	7421-39-4	Endrin aldehyde	1996	31.80	0.0100
10 - FROM RT. 11 OUTFALL PIPE NEAR IRON KETTLE	54774-45-7	c-permethrin	1996	76.60	0.1000
10- 200 M. DOWNSTREAM FROM RT. 11 OVERPASS	72-54-8	4,4' DDT	1995	29.00	0.0100

Table 19. Pesticides found in Letort Spring Run sediment samples, listed by site and color-coded according to pollution category established in Table 17.

Effect of stormwater runoff on macroinvertebrate communities in the Mully Grub and the Letort Spring Run

Using biological communities in streams as indicators of health provides some significant advantages over the use of water column chemistry. Whereas water chemistry samples represent conditions at a single point in time, biological organisms must live in the water over longer periods of time, and therefore represent a time-integrated assessment of conditions. In addition, whereas only individual chemical analytes can be assessed, biological organisms respond to the synergy between chemicals, thus indicating the true ability of the stream to support life. Biological organisms also have certain habitat requirements, and are therefore indicative of the physical and geomorphic state of the stream. For these reasons, scientists have worked towards developing biological criteria for stream health, to supplement and in some cases, supplant the more traditional chemical criteria.

Table 20 and Figure 12 show the abundance of all macroinvertebrate families found at 3 sites in the Mully Grub and 2 sites in the Letort Spring Run, upstream and downstream from the confluence, collected in 1999 (Figure 2, Table 2). Communities in the Mully Grub are dominated by pollution-tolerant macroinvertebrate taxa, such as sewage worms (Tubificidae), bloodworms (Chironomidae), and some molluscs. Absent from or scarce from these communities are the more typical limestone stream taxa such as sowbugs (Ascellidae), scuds (Gammaridae), and mayfly larvae. These communities, when compared to the upstream Letort Spring Run site (site 4), show definite impairment; macroinvertebrate communities in the Letort Spring Run just downstream from the Mully Grub confluence (site 5) show similar impairment (Table 20 and Figure 12).

Table 21 lists the macroinvertebrate families found and their abundances at upstream Letort sites sampled in March of 1995, the Mully Grub sites sampled in March of 1999, and sites in the Letort in the trucking and urban reaches, sampled in March of 1995, in an attempt to place the Mully Grub macroinvertebrates within the context of the Letort Spring Run. Figure 13 is a graph of the abundance of dominant families at these same sites. This figure clearly demonstrates that there is a zone of low abundance of common limestone stream fauna within the Mully Grub and urban reaches, but that these families are abundant in the upstream reaches and that many of these families recover to some degree in the trucking area (Wilderman et al. 1997).

Table 22 is a bioassessment calculation table, using the EPA Rapid Bioassessment Protocol II (Barbour et al. 1999) on all sites in Table 21. Figure 14 is a graphical representation of the metrics used to determine the relative stream health in 4 sections of the Letort Spring Run watershed (upstream, Mully Grub, urban, and trucking). This figure shows that the metrics which indicate healthy streams are lowest in the Mully Grub and urban sections, and the metrics which indicate impacted streams are highest in these same sections. Figure 15 compares the total scores of these four sections; these scores are a function of all 7 metrics used in the analysis. These total scores indicate that the Mully Grub sites are the most impacted of any sites studied; urban sites are next most

PHYLUM	CLASS	ORDER	FAMILY	COMMON NAME	SITE 4 MG Letort, us	SITE 1 MG below Hanover	SITE 2 MG riffle zone, us Bedford	SITE 3 MG baseball fields	SITE 5 MG Letort, ds	Hilsenhoff tolerance
ARTHROPODA	CRUSTACEA	AMPHIPODA	Gammaridae	Scud	10		4			4
		ISOPODA	Asellidae	Sowbug	9					6
	INSECTA	DIPTERA	Chironomidae	Bloodworm				19	9	7
		EPHEMEROPTERA	Baetidae	Mayfly	1					5
			Ephemerellidae	Mayfly	2					1
		COLEOPTERA	Elmidae	Beetle larva	1					5
MOLLUSCA	GASTROPODA	BASOMMATOPHORA	Physidae	Snail			1	1	2	8
		BASOMMATOPHORA	Planorbida	Snail			3	2	2	7
		MESOGASTROPODA	Pleuroceridae	Snail			1			7
	PELECYPODA	VENEROIDA	Sphaeriacae	Fingernail clams			4			8
ANNELIDA	OLIGOCHAETA	TUBIFICINA	Tubificidae	Sewage worm		11				10
	HIRUDINEA	RHYNCHODELLIDA	Glossiphoniidae	Leech				2		8

Table 20. List of all macroinvertebrate families and their abundances found at Sites 1-5 sampled in 1999.

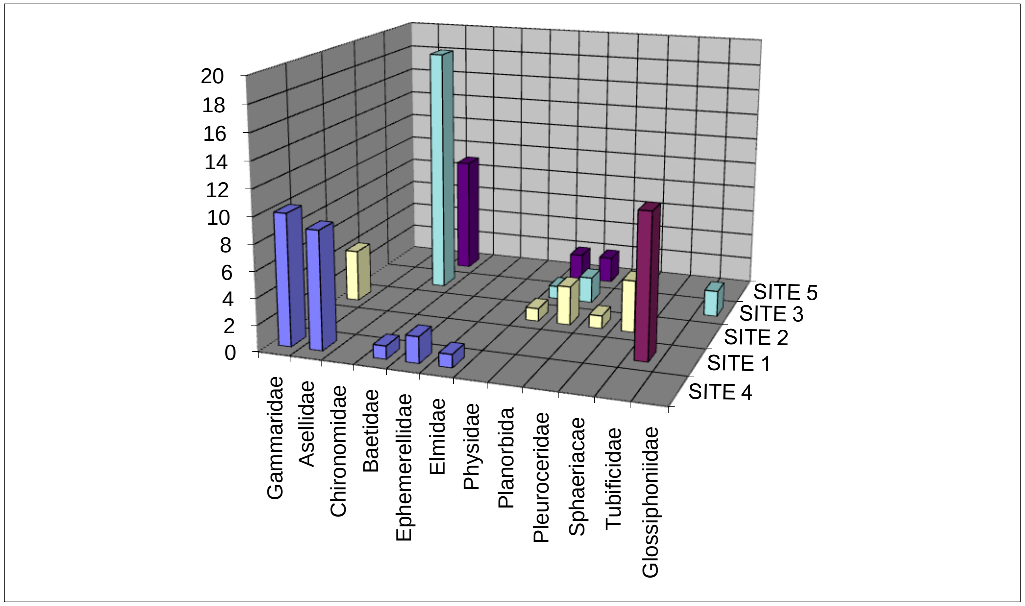


Figure 12. Graph of all macroinvertebrate families and their abundances found at Sites 1-5 sampled in 1999.

ORDER	FAMILY	SITE 1	SITE 5	SITE 6	SITE 9	SITE 11	4-LET	I-MG	2-MG	3-MG	5-LET	SITE15	SITE16	SITE17	SITE18	SITE 19	SITE20	SITE 27	SITE30	Total	Hilsenhoff	Feeding
		US 3/95	US 3/95	US/3/95	US/3/95	US/3/95	3/99	3/99	3/99	3/99	3/99	UR 10/95	UR 10/95	UR 10/95	UR 10/95	TR3/95	TR3/95	TR3/95	TR3/95	no.	tolerance	group
AMPHIPODA	Gammaridae	215	85	321	25	4	10		4			10	14	2	10	95	42	46	19	902	4	CG,SH
ISOPODA	Asellidae	126	55	129	81	43	9					52	1			295	137	30	156	1114	6	CG,SH
DECAPODA	Cambaridae		1		1															2	6	SH
DIPTERA	Tipulidae															1				1	3	SH
	Chironomidae									19	9		1		3	3	1	22	13	71	7	CG
	Simuliidae	1		31	13							1					1			47	6	FC
	Dixidae																	1	3	4	1	CG
	Ephydridae																	1		1	6	PI
	Tabanidae	1																		1	6	PI
	Muscidae-Anthomyiidae	1																		1	6	P
TRICHOPTERA	Hydropsychidae			26	2	3						3			1	38		119	32	224	4	FC
	Limnephilidae		4	1																5	4	SH,SC
	Helicopsychidae				2															2	3	SC
	Phryganeidae		3		1															4	4	SH
	Mystacides		2																	2		
	Platycentropus		1																	1		FC
EPHEMEROPTERA	Baetidae						1														5	CG,SC
	Ephemerellidae	17	5	83	70	100	2					4		1		90	32	48	12	464	1	SC,CG
MEGALOPTERA	Sialidae					1														1	4	P
COLEOPTERA	Elmidae			13	1		1						1							16	5	SC,CG
HEMIPTERA	Corixidae				1															1	5	PI,P
BASOMMATOPHORA	Physidae (Physa)	2	14						1	1	2									20	8	SC,SH
	Planorbidae								3	2	2									7	7	SC
MESOGASTROPODA	Pleuroceridae								1												7	SC
VENEROIDA	Sphaeriidae								4											4	8	FC
ANNELIDA	(unknown)	14	7	4								1	2						3	31	8	P,CG,FC
RHYNCHOBDELLIDA	Glossiphoniidae									2											8	P
TUBIFICINA	Tubificidae							11													10	CG
TOTAL # INDIVIDUALS		377	177	608	197	151	23	11	13	24	13	71	19	3	14	522	213	267	238	2926		

Table 21. List of taxa and number of individuals identified at each macroinvertebrate site in 1995 and 1999. Hilsenhoff tolerance vales and feeding groups are also listed. Site numbers from 1995 correspond to site descriptions in Wilderman, 1997; 1999 sites are described in Table 2 and shown in Figure 2.

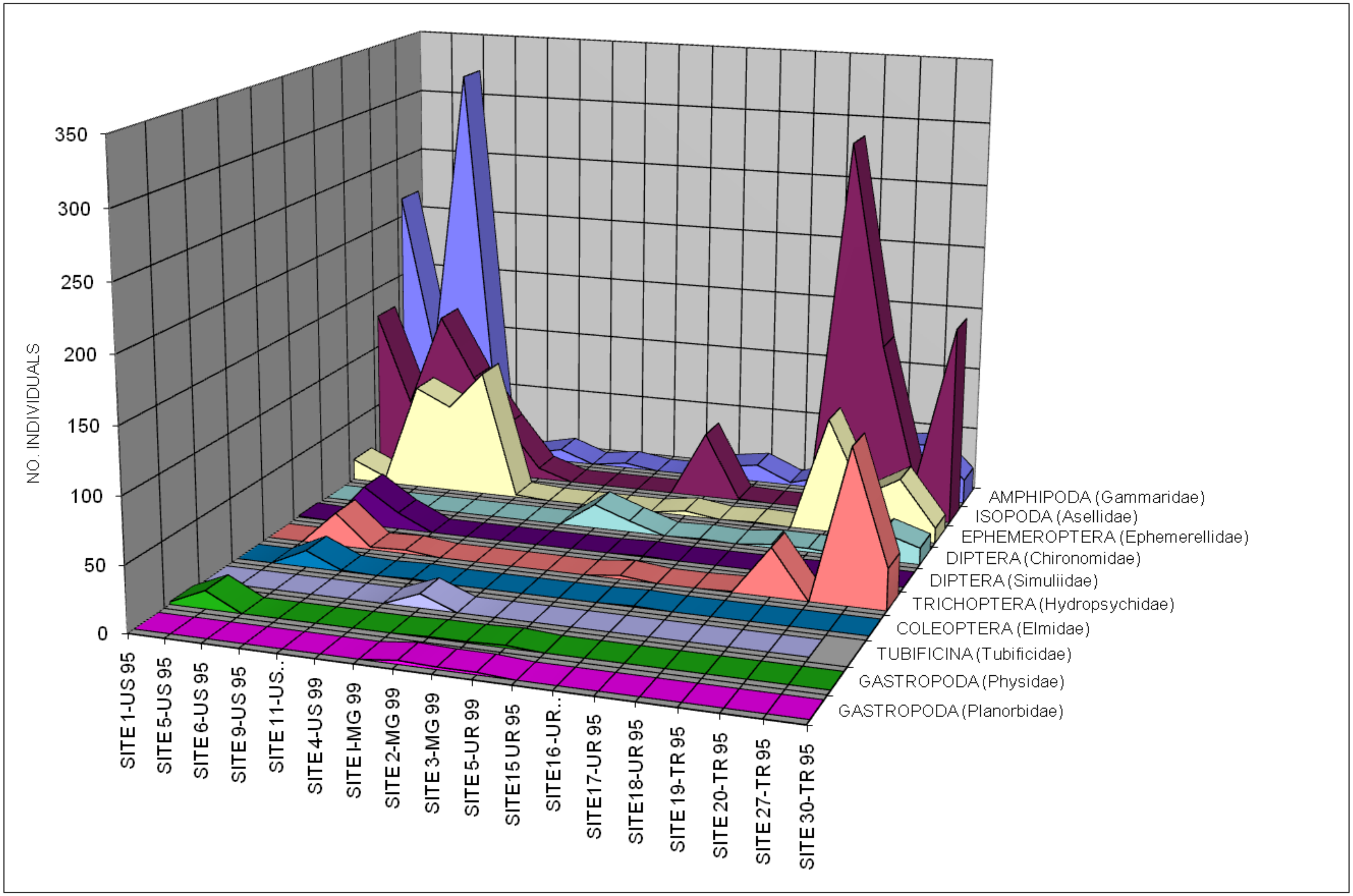


Figure 13. Number of individuals of dominant families of macroinvertebrates in the Letort Spring Run study area, 1995 and 1999. Data are in Table 21.

SITE	SITE 1 US3/95	SITE5 US3/95	SITE 6 US3/95	SITE 9 US3/95	SITE 11 US3/95	4-LET US 3/99	I-MG 3/99	2-MG 3/99	3-MG 3/99	5-LET UR3/99	SITE15 UR10/95	SITE16 UR10/95	SITE17 UR10/95	SITE18 UR10/95	SITE 19 TR3/95	SITE20 TR3/95	SITE 27 TR3/95	SITE30 TR3/95	AVER US	AVER MG	AVER URBAN	AVER TRUCK
				(REF)																		
	UPSTREAM						MULLY GRUB			URBAN					TRUCKING							
										RAW DATA												
Taxa richness	8	10	8	10	5	5	1	5	4	3	6	5	2	3	6	5	7	7	7.67	3.33	3.80	6.25
Hilsenhoff (Family) biotic Index	4.72	4.95	4.16	3.90	2.58	4.61	10.00	6.46	7.13	7.15	5.38	4.74	3.00	4.64	4.63	4.86	3.93	5.34	4.15	7.86	4.98	4.69
Ratio of Scrapers/Filt. collectors	1.00	1.50	1.00	1.50	1.00	2.00	No FC	3.00	No FC	No FC	0.33	1.00	No FC	0.00	1.00	1.00	1.00	0.50	1.33		0.44	0.88
% contrib. of dominant family	57.0	48.0	52.8	41.1	66.2	43.5	100.0	30.8	79.2	69.2	73.2	73.7	66.7	71.4	56.5	64.3	44.6	65.5	51.45	70.00	70.84	57.74
EPT Index	1	5	3	4	2	2	0	0	0	0	2	0	1	1	2	1	2	2	2.83	0.00	0.80	1.75
Community Loss Index	0.40	0.50	0.20	0.00	0.10	1.20	10.00	1.80	2.50	3.33	0.10	0.20	0.00	0.10	0.20	0.10	0.30	0.30	0.40	4.77	0.75	0.23
Ratio of shredders/total	0.38	0.60	0.38	0.40	0.40	0.40	0.00	0.20	0.00	0.00	0.33	0.40	0.50	0.33	0.50	0.40	0.29	0.29	0.43	0.07	0.31	0.37
										PERCENT OF REFERENCE STATION												
Taxa richness	80.0	100.0	80.0	100.0	50.0	50.0	10.0	50.0	40.0	30.0	60.0	50.0	20.0	30.0	60.0	50.0	70.0	70.0	76.67	33.33	38.00	62.50
Hilsenhoff (Family) biotic Index	82.6	78.7	93.6	100.0	150.9	84.6	39.0	60.3	54.7	54.5	72.5	82.3	129.9	84.0	84.2	80.2	99.2	73.1	98.40	51.34	84.64	84.19
Ratio of Scrapers/Filt. collectors	66.7	100.0	66.7	100.0	66.7	133.3		200.0			22.2	66.7		0.0	66.7	66.7	66.7	33.3	88.89		29.63	58.33
% contrib. of dominant family	57.0	48.0	52.8	41.1	66.2	43.5	100.0	30.8	79.2	69.2	73.2	73.7	66.7	71.4	56.5	64.3	44.6	65.5	51.45	70.00	70.84	57.74
EPT Index	25.0	125.0	75.0	100.0	50.0	50.0	0.0	0.0	0.0	0.0	50.0	0.0	25.0	25.0	50.0	25.0	50.0	50.0	70.83	0.00	20.00	43.75
Community Loss Index	0.4	0.5	0.2	0.0	0.1	1.20	10.00	1.80	2.50	3.33	0.1	0.2	0.0	0.1	0.2	0.1	0.3	0.3	0.40	4.77	0.75	0.23
Ratio of shredders/total	93.8	150.0	93.8	100.0	100.0	100.0	0.0	50.0	0.0	0.0	83.3	100.0	125.0	83.3	125.0	100.0	71.4	71.4	106.25	16.67	78.33	91.96
										SCORES												
Taxa richness	3.0	6.0	3.0	6.0	3.0	3.0	0.0	3.0	3.0	0.0	3.0	3.0	0.0	0.0	3.0	3.0	3.0	3.0	4.00	2.00	1.20	3.00
Hilsenhoff (Family) biotic Index	3.0	3.0	6.0	6.0	6.0	3.0	0.0	3.0	3.0	3.0	3.0	3.0	6.0	3.0	3.0	3.0	6.0	3.0	4.50	2.00	3.60	3.75
Ratio of Scrapers/Filt. collectors	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	6.0	6.0	0.0	6.0	6.0	6.0	3.0	6.00	6.00	3.60	5.25
% contrib. of dominant family	0.0	3.0	0.0	3.0	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	1.50	1.00	0.00	0.75
EPT Index	0.0	6.0	3.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.50	0.00	0.00	0.00
Community Loss Index	6.0	3.0	6.0	6.0	6.0	3.0	0.0	3.0	3.0	3.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.00	2.00	5.40	6.00
Ratio of shredders/total	6.0	6.0	6.0	6.0	6.0	6.0	0.0	6.0	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.00	2.00	4.80	6.00
TOTAL SCORES	24.0	33.0	30.0	39.0	27.0	24.0	6.0	24.0	15.0	12.0	18.0	24.0	24.0	15.0	24.0	24.0	30.0	21.0	29.5	15.0	18.6	24.8
% REFERENCE SCORE	61.5	84.6	76.9	100.0	69.2	61.5	15.4	61.5	38.5	30.8	46.2	61.5	61.5	38.5	61.5	61.5	76.9	53.8	75.64	38.46	47.69	63.46
BIOASSESSMENT	MOD	NON	MOD	NON	MOD	MOD	SEV	MOD	MOD	SEV-MOD	MOD	MOD	MOD	MOD	MOD	MOD	NON	MOD	NON-MOD	MOD	MOD	MOD-NON

Table 22. Bioassessment calculation table using EPA Rapid Bioassessment Protocl II (Barbour at al. 1999). NON = Non-impaired; MOD = Moderately Impaired; SEV = severely impaired

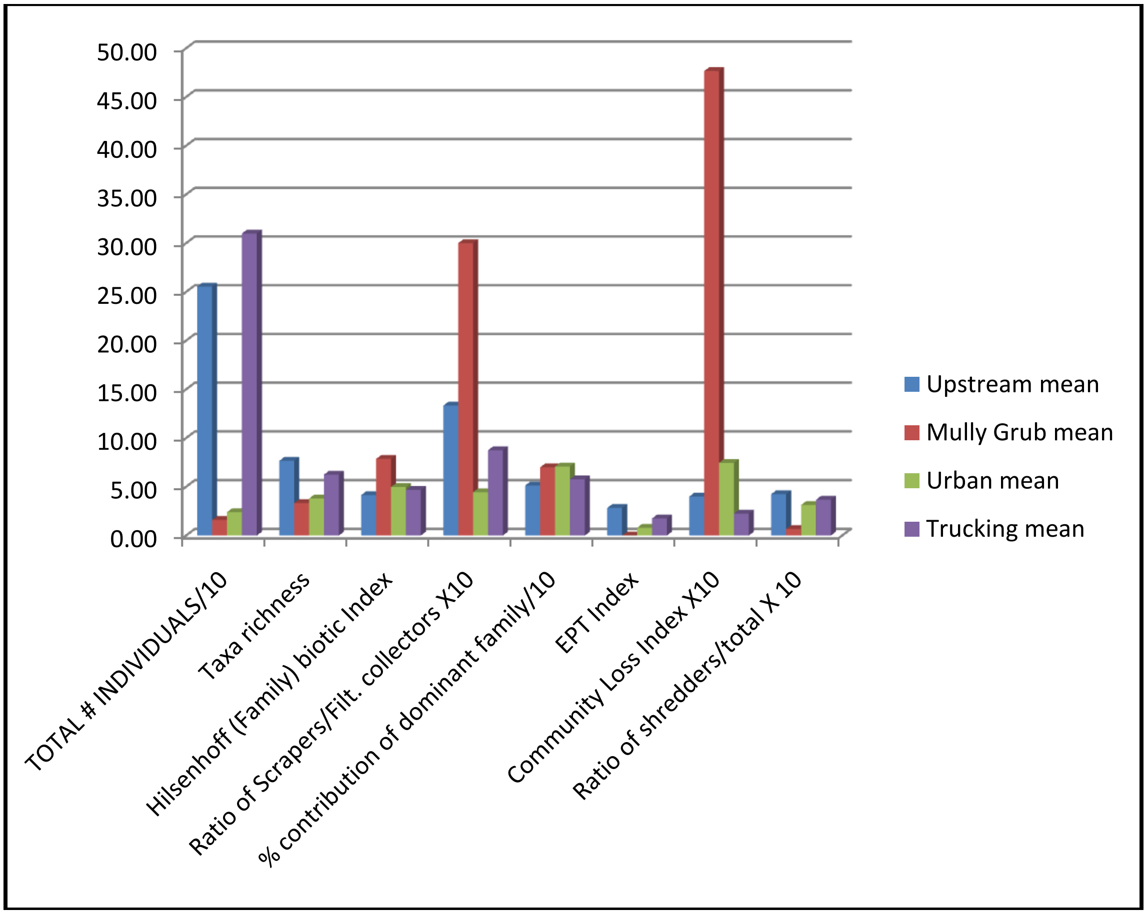


Figure 14. Graphical representation of bioassessment metrics used to determine relative stream health of 4 sections of the Letort Spring Run.

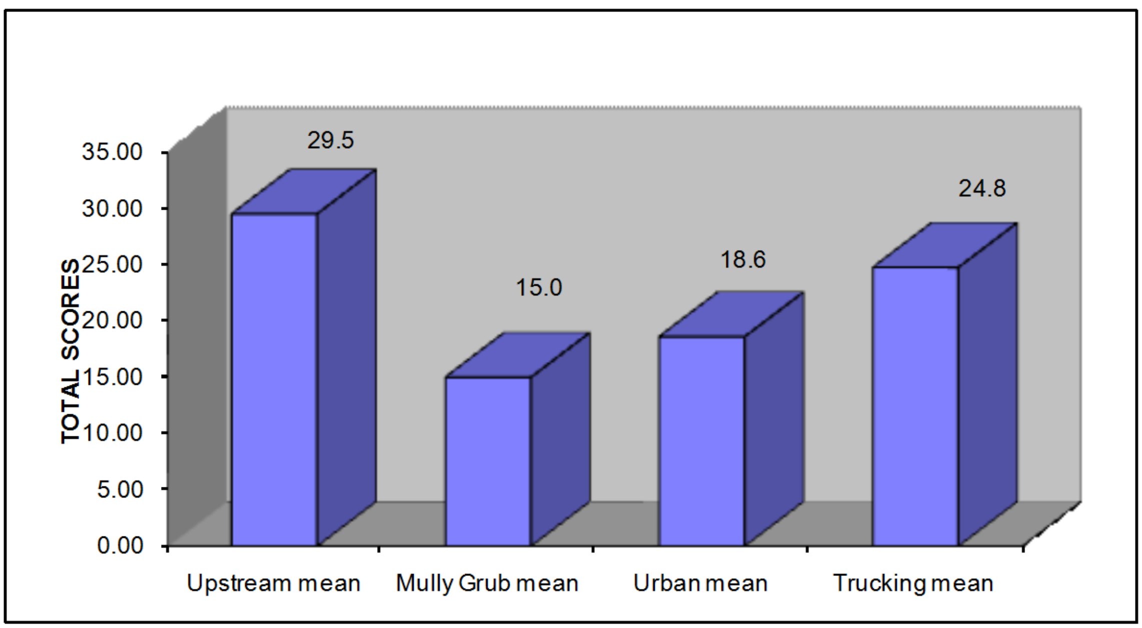


Figure 15. Graphical representation of total scores of 4 stream segments of the Letort Spring Run based on a macroinvertebrate bioassessment.

impacted, followed by the trucking sites. The upstream sites are the healthiest sites based on this multi-metric score.

Macroinvertebrate communities provide another line of evidence that stormwater runoff from urban areas is impacting the Mully Grub. This tributary is the first recipient of these stormwater pollutants; communities within the Mully Grub are even more impacted than the overall urban section of the Letort.

Impact of stormwater runoff on macroinvertebrate habitats

Healthy stream communities require both good water quality and good habitat conditions. For this reason, the same 5 sites from which macroinvertebrates were collected were evaluated for habitat quality in 1999 (United States Environmental Protection Agency 1997). Using the upstream Letort site as the reference site, all sites rated as "poor' for habitat quality (Table 23).

Habitats in the Mully Grub are significantly impacted by the lack of a forested riparian buffer zone to provide shade, leaves, and woody debris, all prerequisites for a functioning stream ecosystem (Sweeney 1993, Bilby and Likens 1980). In addition, sediment influx from stormwater runoff is high, causing the sediment deposition to be extremely high, leaving little substrate for macroinvertebrate attachment. There is no sinuosity nor variability in depth and velocity regimes, and banks are unstable and highly disturbed by high flows during runoff events. Such conditions provide very poor habitat for those groups of macroinvertebrates that are indicators of healthy stream environments. To restore healthy macroinvertebrate communities to the Mully Grub, problems of poor water quality and poor habitat must both be addressed.

Effect of stormwater runoff on diatom communities in the Mully Grub and the Letort Spring Run

The composition and structure of diatom communities have been used extensively to indicate stream health (for example, Dixit et al. 1992, Van Dam et al. 1994). As a biological indicator, diatom communities have the same advantages as macroinvertebrates. However, they also represent a different trophic level from macroinvertebrates, and therefore can be another distinct and useful line of evidence of impact.

Table 24 and Figure 16 show the distribution of diatom genera collected in 1998 from artificial substrates at 5 sites within the study area (Figure 2, Table 2). All of the dominant diatom genera found in the study are tolerant of high nutrient and turbidity conditions (Table 25). Diversity is rather low with one or two genera dominating the communities at each site. Three genera, *Gomphonema, Navicula* and *Synedra* dominate the communities in the Mully Grub overall; all are considered pollution tolerant (Table 25).

*DESCRIPTION OF CRITERIA MUDDY BOTTOM (MB)	ROCKY BOTTOM (RB)	SITE 1 (MB)	SITE 2 (RB)	SITE 3 (MB)	SITE 4 (MB)	SITE 5 (MB)
SHELTER FOR FISH AND MACROS	ATTACHMENT FOR MACROS	1	8	1	13	10
POOL SUBSTRATE	EMBEDDEDNESS	6	2	6	10	7
POOL VARIABILITY	SHELTER FOR FISH	1	0	0	15	6
CHANNEL ALTERATION	CHANNEL ALTERATION	2	2	0	8	8
SEDIMENT DEPOSITION	SEDIMENT DEPOSITION	1	1	0	9	7
CHANNEL SINUOSITY	VEL AND DEPTH COMBINATIONS	0	7	0	7	4
CHANNEL FLOW	CHANNEL FLOW	5	7	5	14	14
BANK VEGETATIVE PROTECTION	BANK VEGETATIVE PROTECTION	1,4	2,2	2,1	10,1	2,2
BANK CONDITION	BANK CONDITION	0,1	1,1	1,1	7,8	1,1
RIPARIAN ZONE WIDTH	RIPARIAN ZONE WIDTH	1,1	1,1	0,0	10,0	0,1

* maximum score for each category = 20

EXCELLENT > 90%	**Habitat Assessment Raw Score**	**24**	**35**	**17**	**112**	**63**
GOOD = 75% - 88%					**(ref)**	
FAIR = 60% - 73%	**% Reference Site**	**21.4%**	**31.3%**	**15.2%**	**100.0%**	**56.3%**
POOR < 58%	**Category**	**Poor**	**Poor**	**Poor**		**Poor**

Table 23. Results of habitat assessments for 5 sites in the Mully Grub and the surrounding Letort Spring Run.

	SITE 4 Letort, us	SITE 1 MG below Hanover	SITE 2 MG riffle zone, us Bedford	SITE 3 MG baseball fields	SITE 5 Letort, ds
Cocconeis	19.4	0.0	0.0	1.3	12.8
Gomphonema	6.0	6.3	36.0	16.5	0.0
Melosira	64.2	4.2	4.0	12.7	27.7
Meridion	0.0	64.6	0.0	0.0	0.0
Navicula	0.0	14.6	0.0	13.9	17.0
Synedra	10.4	10.4	60.0	55.7	42.6

Table 24. Numbers and percentages of diatom genera found at 5 sites in the Mully Grub and surrounding Letort Spring Run. Numbers are percentages of each genus in the entire community.

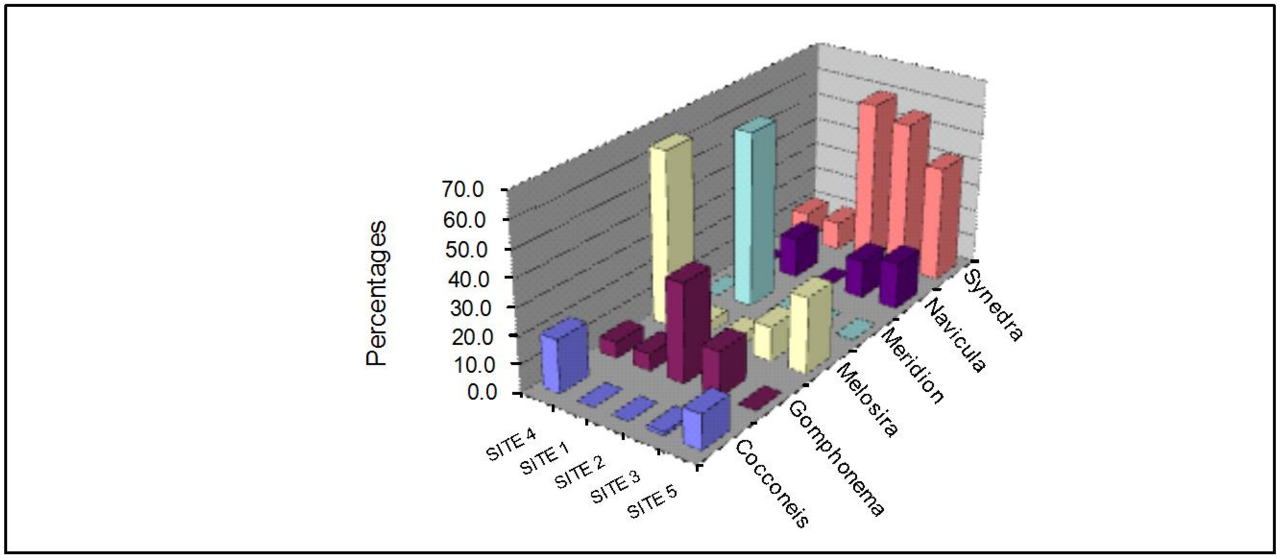


Figure 16. Distribution of dominant diatom genera at the 5 sites in the Mully Grub field study. See Table 2 and Figure 2 for the description and location of sites.

Genus	Preferred Habitat	Environmental Preferences
Cocconeis	epiphytic: grows on leaves of aquatic plants and on filamentous algae	occurs in waters of high turbidity prefers high nutrient concentrations becomes very common in waters with high nitrates
Gomphonema	benthic and epiphytic	can tolerate high metal concentrations prefers waters with nutrients
Melosira	planktonic and epiphytic	dominant in spring blooms becomes more common as a result of increasing nutrients occurs in waters of moderate turbidity
Meridion	benthic and epiphytic	likes water rich in carbon dioxide and bicarbonates (spring water)
Navicula	benthic	indicator of polluted water lives in or on the sediment blooms in the presence of high phosphates and nitrates needs lots of sunlight occurs in water of high turbidity
Synedra	planktonic	dominant in spring blooms occurs in water of moderate turbidity prefers water with high phosphate concentrations

Table 25. Ecological characteristics of the most common and dominant diatom genera in the Mully Grub (data based on Patrick and Reimer 1966, 1975).

Two genera, *Cocconeis* and *Melosira* dominate the communities in the upstream Letort , but are rare in the Mully Grub (Table 24, Figure 16). Both of these genera are epiphytic (Table 25); since submerged aquatic vegetation is abundant in the upstream reaches of the Letort, but rare in the urban reach, there is simply little appropriate habitat for these genera in the urban reach below the confluence of the Mully Grub and the Letort Spring Run.

Meridion, found almost exclusively at the Hanover St. outfall (Table 24, Figure 16) is known for preferring water rich in carbon dioxide and bicarbonates, typical of limestone spring water (Table 25). Since the Mully Grub begins in a series of limestone springs and consists solely of spring water between rain or snowmelt events, it is not surprising that this genus would dominate at the first site where the Mully Grub emerges from its underground journey.

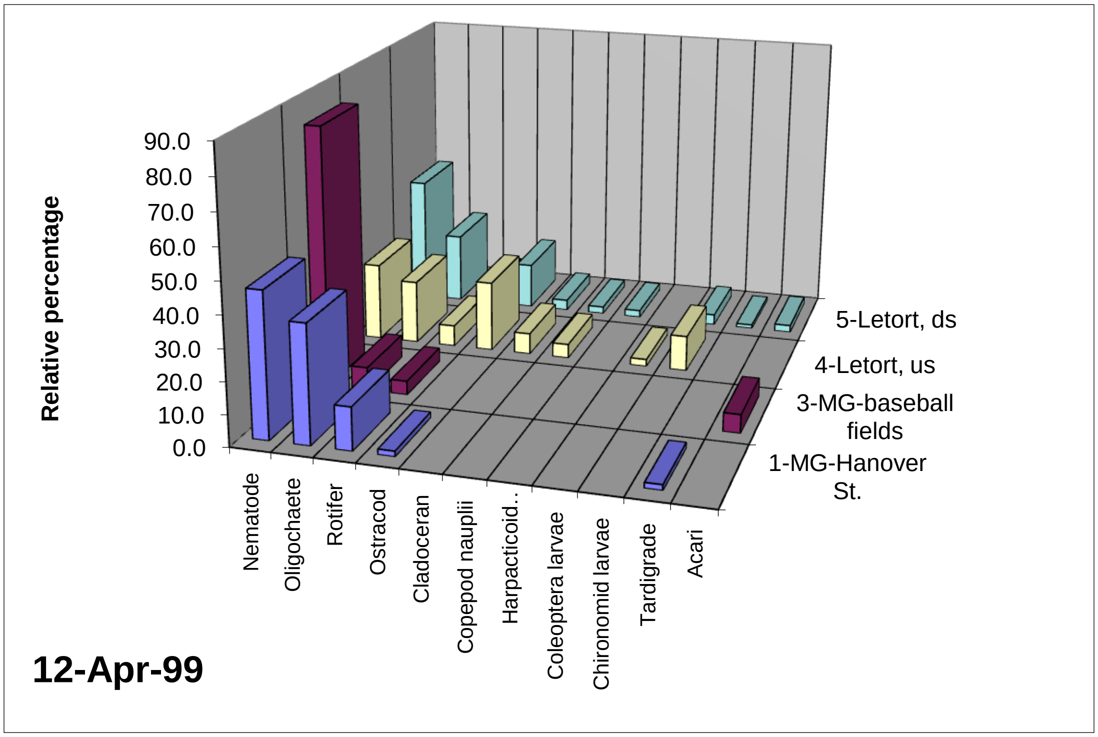
In general, the diatoms indicate that the Mully Grub is not capable of supporting a diverse and pollution-sensitive flora. This may be the result of poor habitat as well as degraded water quality and corroborates other biotic and physical evidence in this study.

Effect of stormwater runoff on meiofaunal communities in the Mully Grub and the Letort Spring Run

Meiofauna are a diverse group of benthic invertebrates, 42-500 um in size, which can contribute significantly to stream ecosystem processes. They are generally present in the first few centimeters of sediment, and are very patchy in their distribution (Giere 1993). Their role in stream ecosystems has been shown to be significant; for example, a single species of meiofaunal copepod was shown to have the same production as that of the dominant macrobenthic shredder in a headwater stream (Palmer and Strayer 1996). Meiofaunal communities can be high in numbers and diversity and constitute greater than 95% of all benthic animals in a stream. Nonetheless, they are often ignored by stream ecologists.

Figure 17 shows the relative abundance of meiofaunal organisms found in the Mully Grub and the Letort Spring Run on April 12 and April 19, 1999. Raw data are found in Table 26. Nematodes, oligochaetes and rotifers are the dominant taxa at all sites in all sampling periods, which is consistent with common phyla reported for freshwater meiobenthic communities (Palmer and Strayer 1996). Ostracods and chironomid larvae are abundant at sites 4 and 5 (Letort Spring Run), but not at sites 1 and 3 in the Mully Grub. Site 3 has the highest percentage of nematodes on both dates.

The Pielou diversity indices (Table 27) show a greater community diversity in the Letort sites than in the Mully Grub sites for both sampling dates. Also on both sampling dates, Site 3 in the Mully Grub (the baseball fields) has the lowest diversity of all sites sampled. There is not a definite degradation in the Letort meiofaunal community after the confluence with the Mully Grub and so the Mully Grub's influence on the meiofaunal community composition in the Letort is unclear.



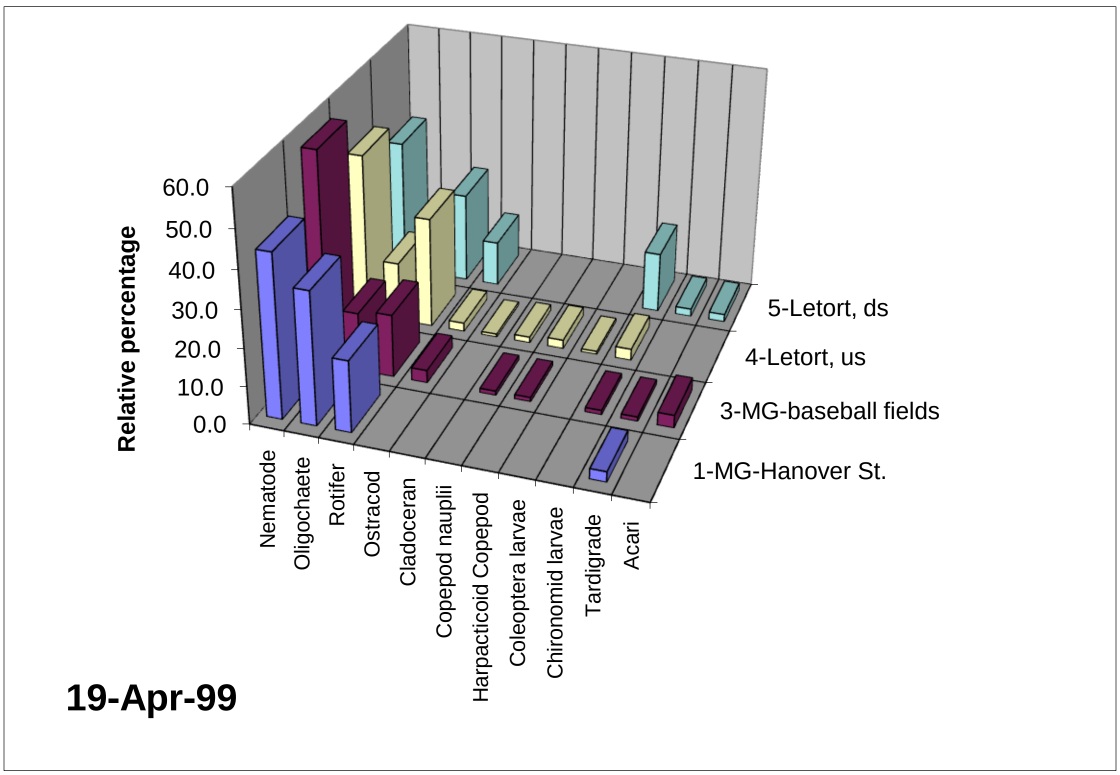


Figure 17. Relative abundance of meiofauna on April 12 and April 19, 1999. Numbers represent pooled values of three samples at each site.

12-Apr-99	NUMBERS												PERCENTAGES										
site	Nematode	Oligochaete	Rotifer	Ostracod	Cladoceran	Copepod nauplii	Harpacticoid Copepod	Coleoptera larvae	Chironomid larvae	Tardigrade	Acari	total # individuals	Nematode	Oligochaete	Rotifer	Ostracod	Cladoceran	Copepod nauplii	Harpacticoid Copepod	Coleoptera larvae	Chironomid larvae	Tardigrade	Acari
1-MG-Hanover St.	27	22	8	1	0	0	0	0	0	1	0	59	45.8	37.3	13.6	1.7						1.7	
3-MG-baseball fields	56	5	3	0	0	0	0	0	0	0	4	68	82.4	7.4	4.4								5.9
4-Letort, us	11	9	3	10	3	2	0	1	5	0	0	44	25.0	20.5	6.8	22.7	6.8	4.5		2.3	11.4		
5-Letort, ds	36	20	6	13	3	2	2	0	3	1	2	88	40.9	22.7	6.8	14.8	3.4	2.3	2.3		3.4	1.1	2.3

19-Apr-99																							
site	Nematode	Oligochaete	Rotifer	Ostracod	Cladoceran	Copepod nauplii	Harpacticoid Copepod	Coleoptera larvae	Chironomid larvae	Tardigrade	Acari	total # individuals	Nematode	Oligochaete	Rotifer	Ostracod	Cladoceran	Copepod nauplii	Harpacticoid Copepod	Coleoptera larvae	Chironomid larvae	Tardigrade	Acari
1-MG-Hanover St.	16	13	7	0	0	0	0	0	0	1	0	37	43.2	35.1	18.9							2.7	
3-MG-baseball fields	51	14	15	3	0	1	1	0	1	1	3	90	56.7	15.6	16.7	3.3		1.1	1.1		1.1	1.1	3.3
4-Letort, us	58	21	39	3	1	2	3	1	4	0	0	132	43.9	15.9	29.5	2.3	0.8	1.5	2.3	0.8	3.0		
5-Letort, ds	18	4	12	6	0	0	0	0	8	1	1	50	36.0	8.0	24.0	12.0					16.0	2.0	2.0

Table 26. Numbers and relative percentages of benthic meiofauna at 4 sites in the Mully Grub study.

The statistical significance (α = 0.10) of the diversity indices of the 4 sites varies with sampling period (Table 27). The sites sampled on April 12 suggests a significant difference in diversity only between sites 1 and 4 and sites 3 and 4, but these differences are no longer statistically significant (α = 0.10) on the April 19 sampling.

Many studies that use meiofauna as pollution indicators employ nematode/harpacticoid copepod ratios. Nematodes are associated with short detrital/bacterial-based food chains and are relatively independent of substrate type, while harpacticoid copepods are associated with microalgal-based food chains and require porous, high-oxygen substrate. An increase in organic pollution will increase the nematode population and decrease the harpacticoid copepod population (Giere 1993). Using this relationship, our data suggest that organic pollution in the Mully Grub is influencing the meiobenthic community by supporting high nematode populations (Figure 17). It is also possible that poor habitat is negatively influencing harpacticoid copepod populations.

The presence of typical meiobenthic assemblages, given their significant role in stream ecosystems, suggests that meiofauna may be playing a role in ecosystem functionality within both the Mully Grub and the Letort. The fact that diversities of meiofaunal communities are significantly lower in the the Mully Grub than in the upstream Letort site on one sampling date, and the dominance of nematodes on both dates corroborates other biological data strongly suggesting a system impacted by organic pollution.

Channel stability analysis—effects of urban flows on stream channel morphology

Urbanization causes an increase in the frequency and duration of bankfull flow events in streams. The net effect is that more bank and bed sediments are moved, triggering a cycle of active bank erosion and greater sediment transport in urban streams (Leopold 1994, Schueler and Holland 2003). As a result, the stream undergoes channel enlargement, and urban streams tend to have a high degree of channel instability (Pizzuto et al. 2000). In fact, Booth (1991) found an inverse relationship between stream bank stability and percent of impervious cover in the Puget Sound area. Erosion from these enlarging stream channels results in high sediment yields; these sediments may move and be deposited downstream where they may seriously impact instream habitat (Trimble 1997).

Table 28 shows the results of an evaluation of channel stability done in 1999 at 3 sites in the Mully Grub and 2 sites in the Letort Spring Run, upstream and downstream from the confluence (Figure 2, Table 2). Total scores indicate that channel stability is poor at two of the Mully Grub sites and the downstream Letort site. Channel stability received fair ratings at Site 2 in the Mully Grub, which is just upstream from Bedford Street, and at the upstream Letort site. Characteristics that were rated poor at many of the sites include: bank slope gradient, mass wasting, vegetative bank protection, lower bank

12-Apr-99

Site	Pielou/Simpson Index
1-MG-Hanover St.	0.643
3-MG-baseball fields	0.316
4-Letort, us	0.838
5-Letort, ds	0.759

t-test matrix

site	2	3	4
1	0.2726	0.0458	0.3605
2	*	0.0956	0.1378
3		*	0.3381
4			*

19-Apr-99

Site	Pielou/Simpson Index
1-MG-Hanover St.	0.688
3-MG-baseball fields	0.647
4-Letort, us	0.711
5-Letort, ds	0.818

t-test matrix

site	2	3	4
1	0.4700	0.7699	0.3549
2	*	0.7771	0.2759
3		*	0.5086
4			*

Table 27. Diversity indices of meiofaunal communities for all sites sampled on April 12 and 19, 1999, pooling data from 3 samples per site. Student t-tests measure the statistical significance of the difference between the mean diversity indices at each site with every other site.

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
UPPER BANKS					
SLOPE	8	8	8	8	8
MASS WASTING	12	9	12	9	12
DEBRIS JAM POTENTIAL	4	2	2	4	4
VEGETATIVE BANK PROTECTION	12	9	12	9	12
TOTAL	**36**	**28**	**34**	**30**	**36**
LOWER BANKS					
CHANNEL CAPACITY	1	1	1	4	4
BANK ROCK CONTENT	8	8	8	4	6
OBSTRUCTIONS	2	2	2	4	4
CUTTING	12	16	16	12	6
DEPOSITION	16	12	16	16	16
TOTAL	**39**	**39**	**43**	**40**	**36**
BOTTOM					
ROCK ANGULARITY					
BRIGHTNESS					
PARTICLE PACKING	8	4	8	4	4
% STABLE MATERIALS	16	12	16	12	16
SOURING AND DEPOSITION	24	18	24	18	24
CLINGING AQUATIC VEGETATION	4	4	4	3	4
TOTAL	**52**	**38**	**52**	**37**	**48**
TOTAL CHANNEL STABILITY SCORE	***127***	***105***	***129***	***107***	***120***

EXCELLENT < 36
GOOD = 36-72
FAIR = 73-108
POOR > 108

Table 28. Pfankuch channel stability assessments at 5 sites in the study area. Refer to Figure 2 for study site locations.

rock content, cutting of lower banks, deposition, particle packing, percentage of stable materials, scouring and deposition, and clinging aquatic vegetation. In short, almost all characteristics that are rated by Pfankuch's methodology (Pfankuch 1975) were given poor ratings in the sites assessed, as might be expected in a highly urbanized stream.

PART II:
THE MULLY GRUB RESTORATION/MITIGATION PROJECT

INTRODUCTION

Using multiple lines of evidence, the Dickinson College student studies indicate that urban runoff from the town of Carlisle is adversely impacting both the Mully Grub and its receiving stream, the Letort Spring Run. Armed with this knowledge, the students targeted the Mully Grub for a restoration project. Reasons for choosing the Mully Grub include:

- The Mully Grub is the first major urban outfall into the Letort Spring Run and marks the upstream end of the impaired urban reach.

- The Mully Grub is the only urban stormwater outfall in the watershed that flows over ground for a distance before entering the Letort. It therefore has visibility, access to the public, and some land area in which to place a mitigation project.

- The confluence of the Letort and the Mully Grub is just across from the Letort Park, Carlisle's central urban park.

- The location of the Mully Grub makes it an ideal location for environmental education and awareness-raising. Its proximity to the school and the Borough playing fields provides an opportunity for the school children to participate in the project and to utilize the grounds as a laboratory. The proposed project provides an excellent opportunity for the community to strengthen their sense of stewardship for common resources.

- This project could act as a model to other urban communities who are concerned about stormwater runoff and its effects on their neighborhood resources.

The constraints involved in restoring the Mully Grub to a fully functioning ecosystem are substantial. The stream itself has been channelized for at least 140 years, and flows through an area that has been filled with foundry sand. Fences that delineate the school playground and the Borough's baseball fields confine the riparian zone to approximately 3-4 meters on each side of the stream. The area receives heavy use from neighborhood residents, and there is a high risk of vandalism at the site. Recognizing that full restoration was not possible, goals for mitigation of the effects of the urban runoff were established; in addition, students recognized the criticality of involving the community in these restoration efforts (Chopyak 2001).

The goals that the students established at the start of the mitigation efforts are as follows:

- To improve the water quality and habitat in the Mully Grub so that it no longer impacts the Letort Spring Run.

- To improve the water quality and habitat in the Mully Grub so that ecosystem functionality is increased.

- To increase the visual appeal of the site, in order to increase the community's sense of caring, pride, and motivation to maintain the project.

- To involve the community in the project to minimize the cost, to promote educational awareness, to insure long-term maintenance, assessment, and care, to build a sense of stewardship and ownership of the property, and to build community capacity for future projects.

- To provide an environmental laboratory for the local school for continued environmental education of the children.

- To provide a model for other community-based urban restoration/mitigation projects.

DESCRIPTION OF THE RESTORATION PROJECT

Components of the Student Restoration/Mitigation Plan

Figure 18 is a hand-drawn map of the original student conceptualization of a desirable and realistic mitigation plan. Table 29 lists the most important components of the plan, the pollution problems that they are designed to address, and the community amenities that they could provide. Numbers next to the design components correspond to the numbers on the map in Figure 18. Students felt strongly that plans should also be made to involve a wide variety of community stakeholders in the planning and implementation of the project

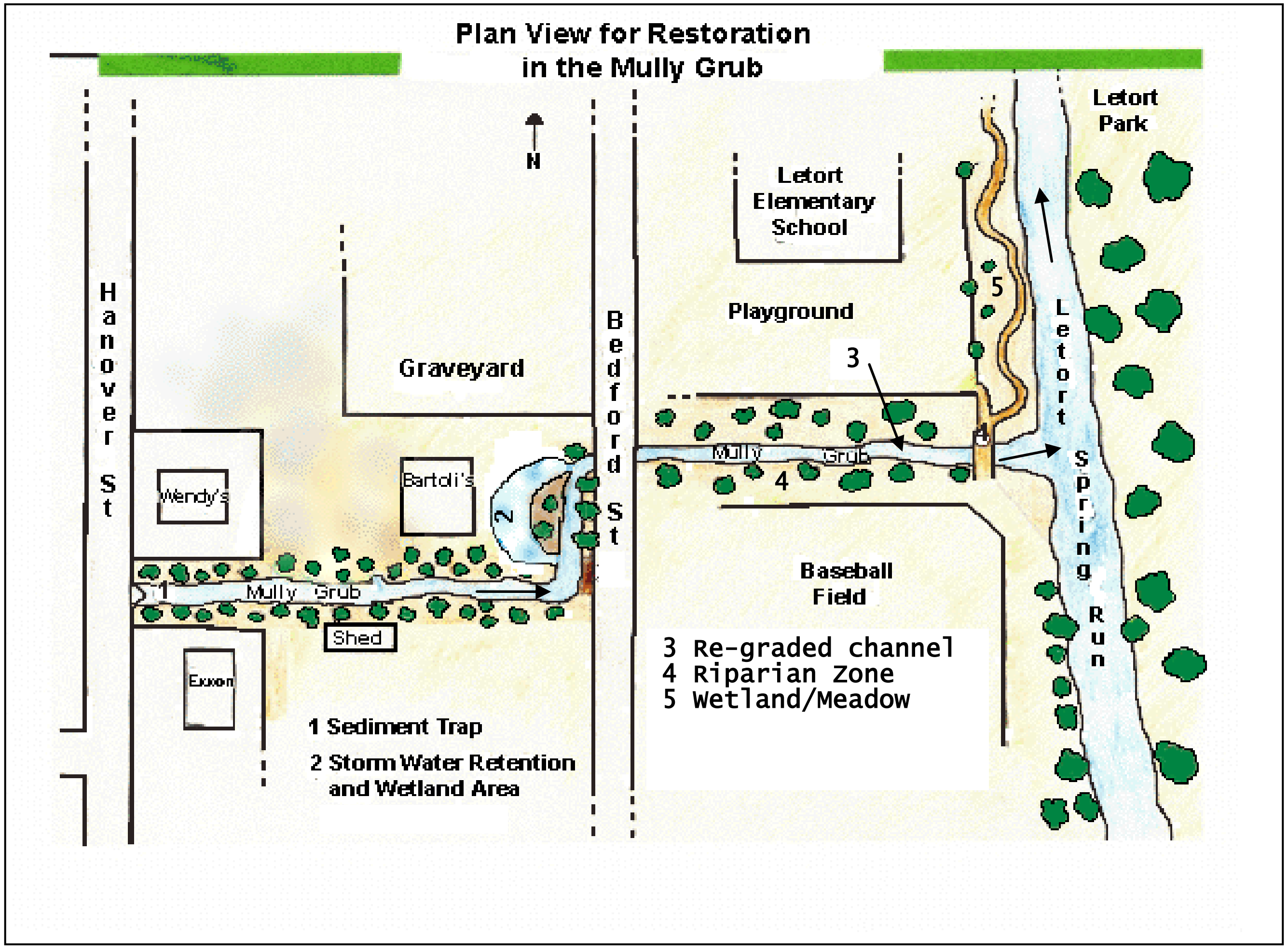


Figure 18. Original drawing of student conceptual mitigation plan for the Mully Grub.

Design component	*Pollution problems component is designed to address*	*Community amenity*
1- Sediment traps installed on storm drains upstream from where the MG emerges from under the ground	Provides small sediment settling chambers, where sediment and the pollutants clinging to it will be removed	Clearer water in the most upstream section of the MG, for aesthetic enjoyment.
2 - Constructed wetland/retention pond	Receives storm water at high flows; provides settling basin for sediment and metal removal; allows time for PHC to evaporate and non-volatile components to settle; plants remove pollutants from water column; provides storage for high flow conditions	Provides habitat for wetland species, including amphibians, reptiles, and birds. Provides an educational laboratory for the local school and community groups.
3 - Redesigned and regraded channel; stabilized banks through seeding, mulching, and planting of pre-planted stabilogs	Increasing bank stability decreases erosion and sediment load during high flows; redesigning channel shape conveys flow more effectively	Provides safer entry for children and teachers into creek. More aesthetic, more clarity in stream.
4 - Riparian zone restoration	Planting of native trees and shrubs provides a healthier riparian buffer zone, which ultimately will uptake excess nutrients and provide shade, leaves, and woody debris to the MG for improved habitat and ecosystem functioning	Provides shade for activities, a wildlife corridor, and an aesthetic walkway.
5 - Wetland meadow[5] along Letort Spring Run	Provides functional riparian buffer zone and if designed properly, can discourage too much nesting by waterfowl	Provides habitat for wetland species and an educational laboratory for the school.

Table 29. A list of the components of the student-conceived mitigation project.

Funding for the proposed mitigation plan

In the spring of 1999, students presented the results of their scientific studies and their plan for mitigation of the Mully Grub to members of the Letort Regional Authority (LRA) and to the Director and staff of the Alliance for Aquatic Resource Monitoring

[5] This wetland meadow was the only aspect of the proposed student plan that did not get funded.

(ALLARM).[6] Convinced of the environmental and social value of this proposed restoration project, the LRA and ALLARM agreed to submit a grant proposal to the Pennsylvania Department of Environmental Protection (DEP) under Section 319 of the Nonpoint Source Management Program. The data from the student study were used to justify the need for the mitigation project, and the grant proposal was approved in September of 1999.

The 319 Grant provided most of the funding ($22,450) for Phase I of the restoration project. Funds were also provided by the GB Stuart Charitable Foundation and in-kind contributions were provided by Gleim Environmental Group, Walter Heine Associates, and Dickinson College, totaling $16,394. Phase I was conducted from September, 1999 to December, 2000, for a total cost of $38,844.

The monies received through the Section 319 program from DEP were not sufficient to construct the wetland proposed in the student plan. As mentioned earlier, the PA Fish and Boat Commission (PAFBC) and the Letort Regional Authority (LRA) had earlier identified the need to improve instream fish habitat in the Letort Spring Run near the Mully Grub confluence, to promote public use of the area flowing through Letort Park. To these ends, ALLARM partnered with these two agencies in taking the lead in a second grant proposal to the PA DEP Growing Greener program. Additional partners in this effort included the Civil and Environmental Design Group, The Carlisle Area School District, the Borough of Carlisle, Dickinson College, individual volunteers, environmental groups, and local property owners, all of whom made in-kind contributions. Monies were also contributed by PAFBC and the LRA ($12,000). The grant monies from PA DEP were received ($140,000) and Phase II of the project was implemented from May 2000 through June 2002, for a total cost of $152,000.

The physical improvements

Phase I

Phase I of the restoration project involved implementation of the first three design components of the student plan: 1) the installation of sediment traps in storm drains, 2) channel reconstruction and bank stabilization, and 3) riparian zone restoration (Table 29, Figure 18).

[6] The Alliance for Aquatic Resource Monitoring (ALLARM) is a project of the Environmental Studies Department at Dickinson College. Staffed by professional staff, faculty, and students, ALLARM provides capacity-building programmatic and scientific assistance to watershed groups concerned with the protection and restoration of their aquatic resources. ALLARM's goals are two-fold: 1) to enhance local action for the protection and restoration of Pennsylvania watersheds by empowering communities with tools to carry out watershed assessments, to interpret data, and to take action, and 2) to provide opportunities for students to participate in community-based participatory research, thereby enhancing the quality and relevance of their undergraduate science educations.

Four sediment traps were installed in storm drains in areas just prior to where the Mully Grub emerges from its journey through the storm drain system in Carlisle, into the channel. The purpose of these traps is to allow the initial settling of the storm water, to help remove sediments and their accompanying pollutants. These traps were installed by the Carlisle Borough maintenance crews, and are being maintained on a regular basis by them. The hope is that trapping some sediment before the Mully Grub emerges from underground will remove some of the pollutants documented by the student study and result in higher water quality in the Mully Grub and less conveyance of pollutants to the Letort Spring Run.

The students documented that channel stability was poor in the portion of the Mully Grub that flows from Bedford Street to the mouth, resulting in continual collapse of the banks and downstream transport of sediments (Hession 2001). To address this issue, the channel was redesigned by the Civil and Environmental Design Group and regraded by the primary contractor, Gleim Environmental Group. Figure 19 shows the engineering design for the new channel configuration, resulting in an overall wider channel with more gently sloping banks; Figure 20 shows photographs of the channel before, during, and after regrading. The banks themselves were stabilized through seeding, mulching, and the installation of "stabilogs," long, cylindrical bound jute fibers, pre-planted with wetland plants (Figure 21). The stabilog project was funded by the GB Stuart Foundation and was the first time this technology was used in Pennsylvania.

Although aerial photographs from the mid-1960's show a fully forested riparian zone along the Mully Grub, these trees were removed soon thereafter and the area has been mowed to the banks ever since. A forested riparian zone is critical to the health of a stream; it provides shade, leaves (which are the energy base of stream ecosystems), woody debris to enhance instream habitat, decreased erosion of banks, increased bank storage to flood control, and nutrient uptake (Sweeney 1993, Schueler 2000). In addition, a riparian zone can provide a wildlife corridor and an aesthetic walkway.

The planting of the riparian zone was done at the same time as the channel modification activities, and involved participation by all partners. Native trees and shrubs were planted in the narrow available riparian zone from Bedford Street to the mouth of the Mully Grub. Trees and shrubs were donated by the Chesapeake Bay Foundation and included 170 plants of the following species: green ash, red maple, silver maple, white oak, pin oak, sycamore, arrowwood, black and red chokeberry, serviceberry, red osier dogwood, and silky dogwood. Figure 22 shows the riparian zone over time, from the initial planting period during the summer of 2000 to the summer of 2004.

The Borough of Carlisle and the Carlisle School District agreed to do the routine maintenance on the riparian buffer zone. In an area that has been mowed down to the bank for over 40 years, it was difficult to convey the importance of not mowing in the riparian zone. The lesson was eventually learned. The first growth season of the riparian zone was wet and the plants got a good start; however the second season was extremely dry and there was significant mortality. Replacement trees and shrubs have been planted

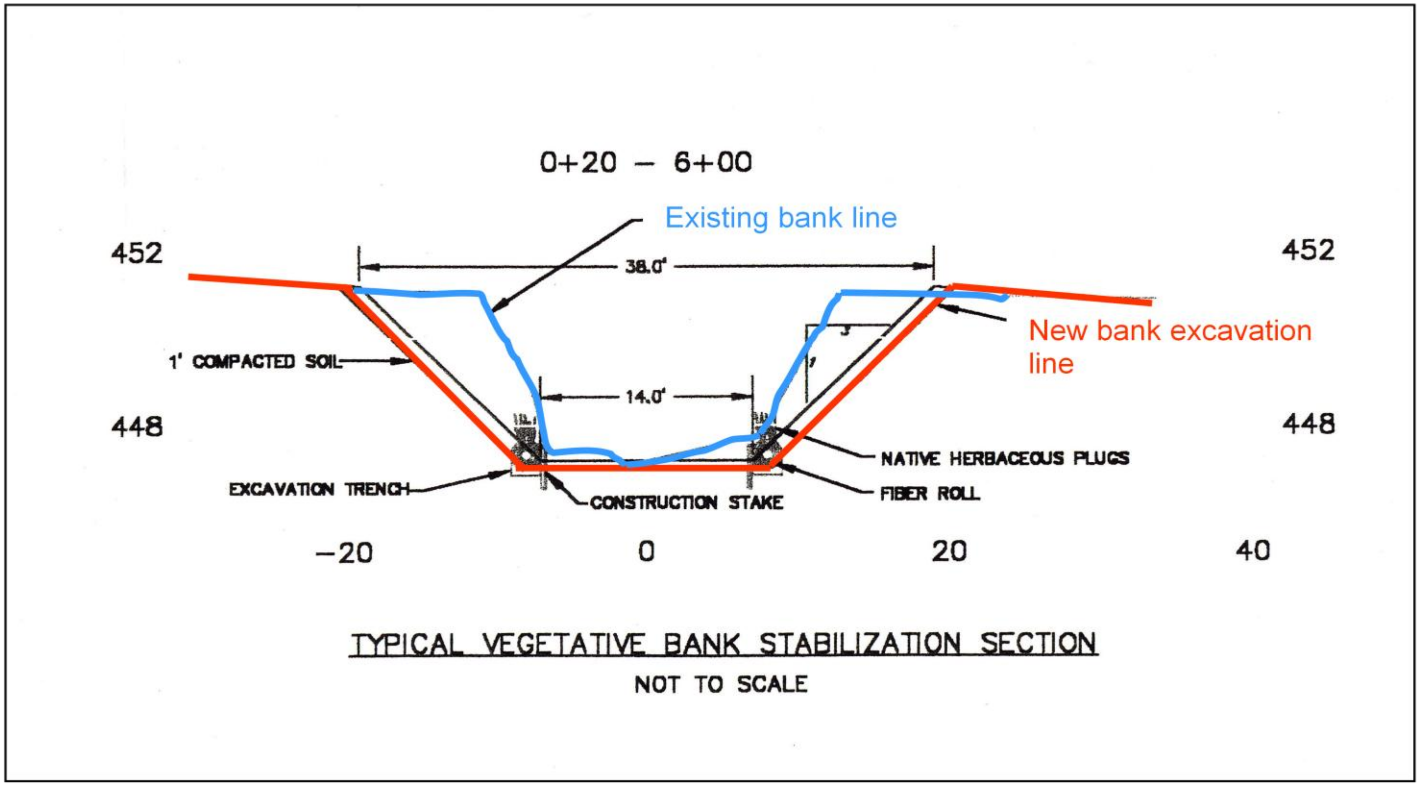


Figure 19. Engineering design by Civil & Environmental Design Group for the new channel configuration.

Figure 20. Photographs of the channel before, during, and after the regrading process. The channel was regraded to increase stability, and then the banks were seeded and mulched, to prevent erosion. Notice the difference in the slope of the channel banks.

Figure 21. Photographs showing the installed "stabilogs" on the banks of the Mully Grub. The stabilogs, or biologs, are pre-planted with wetland plants and used to initiate growth and stabilize banks.

Figure 22. Photographs showing the changes in the riparian zone over time.

by the community on several community planting days. Many of the larger trees are now firmly established.

Phase II

The physical improvements in Phase I were designed to stabilize the channel and to create a riparian buffer zone along the lower section of the Mully Grub to provide increased quality of instream habitat and ecosystem functioning. Nonetheless, the urban pollutants from the town of Carlisle were still being conveyed via the stormwater infrastructure to the Letort Spring Run. While some pollutants were prevented from reaching the Mully Grub by the storm drain sediment traps, these devices are small and are only able to remove a fraction of the pollutants. According to the student conceptual plan, the "powerhorse" of the restoration project was to be the constructed wetland/retention pond, which was to capture pollutants as water was conveyed from the Mully Grub into the wetland. This wetland was finally constructed during Phase II of the restoration project; it was located along the upper reaches of the Mully Grub on property generously donated by James Bartoli.

The wetland was designed by Civil & Environmental Design Group to capture high waters from the Mully Grub through an intake pipe, pass the water into the wetland area, and then release the water through a pipe exiting the wetland just downstream from the intake pipe (Figure 23) (Schueler 1994, Athanas and Stevenson 1991). Wetland vegetation was planted within and surrounding the retention pond; vegetation was installed by a local nursery, Octorora Nurseries. Plants included such native species as soft stem bulrush, dark green bulrush, woolgrass, tussock sedge, soft rush, boneset, pickerel weed, buttonbush, silky dogwood arrowwood, red oak, swamp white oak, willow oak, and scarlet oak.

In the months after the wetland was built, the area experienced a severe drought and many of the plants perished. Emergency water was delivered to help keep some of the seedlings alive, both in the wetland and in the adjacent riparian buffer zone, by the Letort Regional Authority, Gleim Environmental Group and ALLARM. Water was shipped in by the Carlisle Borough to. Although some mortality was experienced, the community has since been involved in augmenting this flora during several community activity days, organized by ALLARM student staff and funded by the Growing Greener grant and a contribution from the Susquehanna River Wetlands Trust (Figure 24). Additional wetland plantings will be done.

It is the hope that as the wetland matures, the area will become an important component of an outdoor laboratory along the Mully Grub for the elementary school students at the adjacent school. Educational signage was purchased through the grant and installed by Dickinson College Department of Facilities Management; these signs describe the purpose of the project and the history of the Mully Grub.

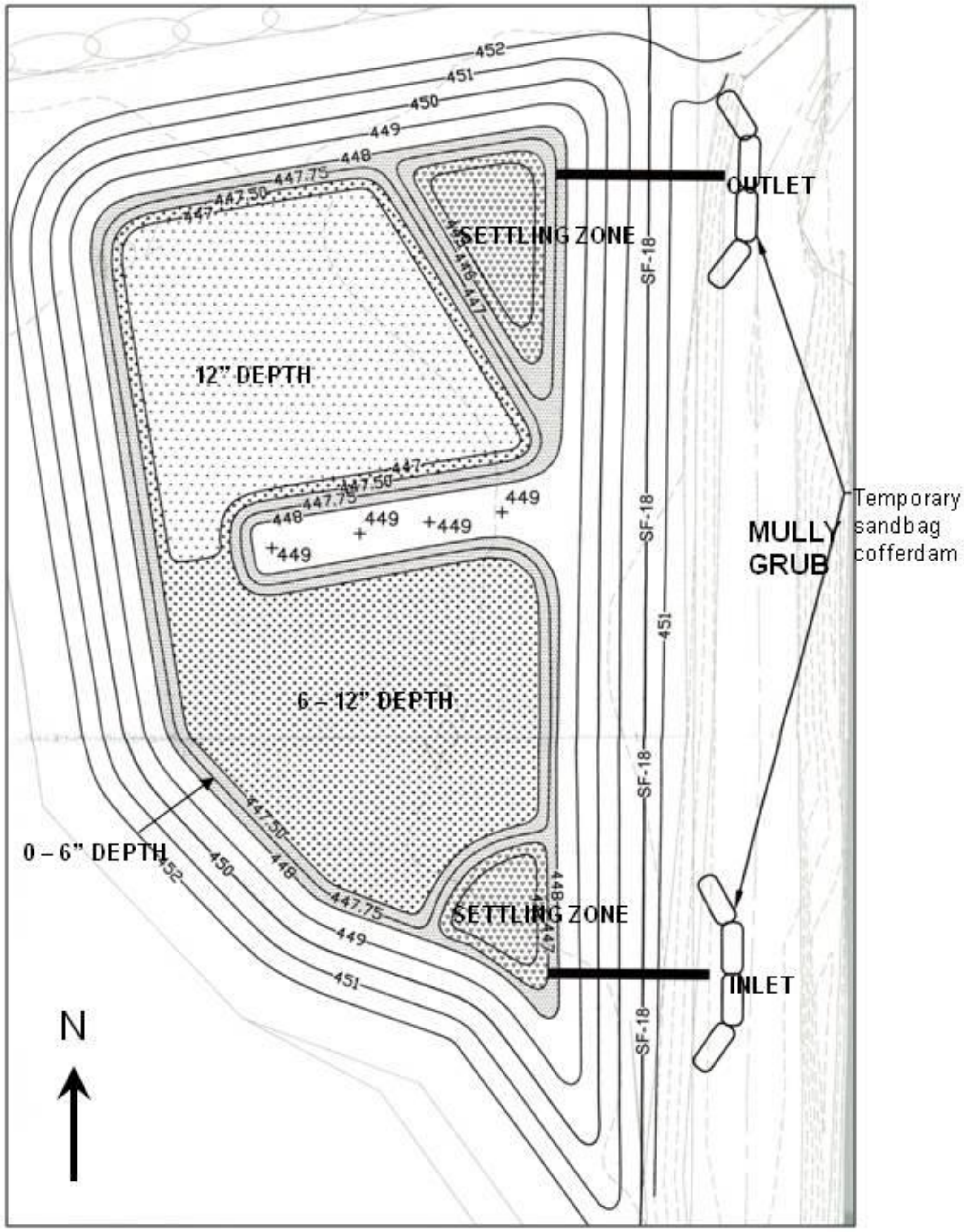


Figure 23. Engineering design by Civil & Environmental Design Group for the constructed wetland/retention pond.

Figure 24. Photographs of the construction and ongoing planting of the wetland/retention pond. The wetland/retention pond is designed to received stormwater at high flows. All plants are native species.

Phase II also included the Letort Spring Run restoration project above and below the Mully Grub confluence, conceived and designed by the PA Boat and Fish Commission and Letort Regional Authority. This project includes the components in Table 30 below. Figure 25 shows pictures of these physical improvements to the Letort Spring Run.

Component	Pollution problems component is designed to address	Community amenity
Stone deflectors	Increase rate of flow which decreases the amount of sedimentation to restore better habitat for macroinvertebrates and for fish spawning; increase flow may also increase dissolved oxygen concentrations.	All of these measures improve habitat for fish spawning, in the hopes that the native brown trout in the upstream sections of the Letort Spring Run will move into this area.
Cedar tree brush deflectors	To trap sediment to restore habitat	These measures are in support of the wheelchair-accessible
Replacement of streambank stone walls with rock	Diffuses energy during high flows and decreases erosion damage; allows for more natural migration of stream	pathways, fishing ramps, and nature trails planned for the urban park.
Wheelchair-accessible pathways, fishing ramps and nature trails in Letort Park	Not designed to address pollution problems.	Allows for increased use of the natural amenities of the Park by all potential users.

Table 30. A list of the components of the mitigation project suggested for the Letort Spring Run, in the vicinity of the confluence of the Mully Grub.

EDUCATION AND OUTREACH

One of the keys to the success of the Mully Grub restoration project lies in the meaningful involvement of a wide variety of community stakeholders, with strong coordination from the ALLARM Director. Figure 26 is a graphical depiction of this structure, with all key players represented. Table 1 shows the functional roles of the key players in the project, from its conception to its completion. This level of involvement of community players was a direct result of an aggressive education and outreach component of the project, managed by ALLARM.

During both phases of the restoration project, student staff members of ALLARM conducted widespread community education and outreach activities. At the start of Phase I, students went into classrooms at the Letort Elementary School and gave lessons on streams, urban runoff, and the Mully Grub. The grade school students made flyers to be

Stone deflectors to increase rate of flow and decrease sedimentation

Cedar tree brush deflectors to trap sediment and create fish spawning habitat

Wheelchair accessible pathways, fishing ramps, and nature trail

Replacement of eroding streamback walls (built in the 1930s by the Civilian Conservation Corps) with large rocks.

Figure 25. Photographs of physical improvements along the Letort Spring Run in the vicinity of Letort Park and of the confluence of the Mully Grub and the Letort Spring Run.

PARTNER GROUPS IN THE RESTORATION PROJECT

Figure 26. Major partners in the Mully Grub restoration project.

placed around town, showing "clean and dirty streams," and announcing a public meeting for community members. During this public meeting, the ALLARM students reported the results of the Dickinson student research, and described the plans to restore the Mully Grub. Attendees were asked for input on critical issues, and many offered in-kind and direct financial support (Figure 27a).

In addition, ALLARM student staff brought seedlings that were donated by the Chesapeake Bay Foundation to be planted in the riparian zone into the elementary school classrooms, where the children established them in pots. Each classroom group potted two seedlings and nurtured them over the winter (Figure 27b). In the spring, they had the opportunity to plant them in the riparian zone, during a community planting day. It was also on this day that the contractors regraded the stream channel, seeded and mulched the banks, and planted biologs, which were pre-planted with wetland plants (and financed by a local foundation). Participants in the riparian zone planting also helped with this process. The Tressler Wilderness School, which works with at-risk youth, brought its students to help play a leadership role in the planting activities for the riparian buffer zone (Figure 27c).

Other outreach and educational activities involved making educational signs for the site and providing numerous tours for visitors from the college, government agencies, and the community. The project was publicized through an "on-the-spot" video made by ALLARM students and through a large town meeting where students explained the project to participants in two separate (and quite elaborate) multi-media shows over the period of the project. Student staff also went into the high schools to make presentations, and did storm drain stenciling with high school students and girl scout troops (Figure 27d).

Now that the construction and initial planting has been completed, students are holding an ongoing series of clean-up, additional planting, and information days for the community. These are being attended by students of all ages, parents, anglers, neighbors, and other interested community members (Figure 27d).

The Letort Regional Authority has taken over the routine maintenance of the wetland. The restoration project has not experienced a great deal of vandalism, considering its location and its history of vandalism. This may be attributed to its increased aesthetic value, as well as the sense of community ownership that comes from involvement in building the project (Wallis 1996). The improved fishing ramps, which are handicapped-accessible, the pathways, and the nature trails in the Letort Park are being heavily used.

It is the hope that, with time and careful maintenance, the biological communities will return to the urban Letort and the Mully Grub, so that anglers can enjoy fishing for naturally reproducing brown trout in the urban park, and so that the children in the schools can have a backyard laboratory. It is also the hope that the wetland will provide sufficient removal of pollutants so that water quality will improve along with habitat. The wetland and riparian zone should attract wildlife, even in their urban setting.

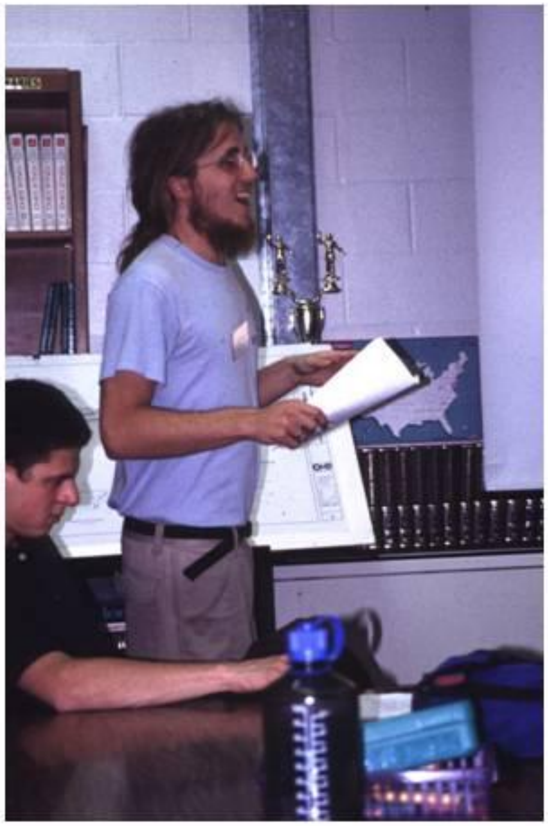


Figure 27a. Dickinson College students report the results of their studies and their plan for mitigation to community members.

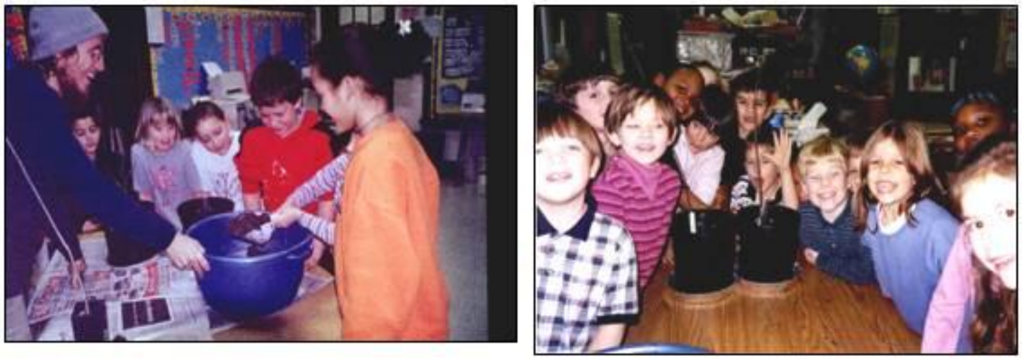


Figure 27b. Dickinson College students plant seedlings in pots with Letort Elementary School students. Elementary school students cared for the seedlings over the winter and planted them in the spring in the Mully Grub riparian zone.

Figure 27c. Local community members, including youth enrolled in the Tressler Wilderness School, plant trees in the riparian buffer zone.

Figure 27d. Public presentations included community celebration days, multi-media presentations, stream clean-ups, and storm stenciling activities with local high school students and girl scouts.

Figure 28 is a timeline of activities involved in this project, from the initial student studies to the present day.

ASSESSMENT OF THE PROJECT

To evaluate the success of the Mully Grub restoration project, an assessment of the extent to which the original goals were met must be performed. Assessment of the project is ongoing and will take years to complete. The following is a summary of the assessment protocols planned or currently in place, and preliminary results, where available, for each goal.

To improve the water quality and habitat in the Mully Grub so that it is no longer impacting the Letort Spring Run.

Student staff of ALLARM at Dickinson College are systematically sampling the Mully Grub and the surrounding Letort Spring Run. They are sampling water column chemistry in the Mully Grub project area on a monthly basis at 5 sites; some sampling dates have been during storm events. In addition sediment samples have been analyzed for lead concentrations by students in the Environmental Chemistry class, with a focus on a comparison of sites upstream and downstream of the wetland. Plans to test for metals in the water column after a major rain event are in place. Instream habitat is being watched and will be evaluated with formal habitat assessments if and when changes become apparent. Channel stability is also being visually assessed, and stream profiles are being constructed once per year by ALLARM student staff. It is too early in this process to draw conclusions about the efficacy of the project in terms of pollution abatement.

To improve the water quality and habitat in the Mully Grub so that ecosystem functionality is increased.

Since it may take years for the ecosystem to respond positively to the changes in water quality and habitat, no evaluation of this has taken place at this time. However, there are plans in place to evaluate biological indicators of ecosystem functionality in the near future. Macroinvertebrate samples will be taken by students from the Mully Grub and the surrounding Letort, to compare with communities prior to the project. In addition, the PA Fish and Boat Commission will sample the Letort in the vicinity of the Letort project to evaluate whether brown trout populations have been favorably impacted.

This coming year a student at Dickinson College will be doing a formal assessment of the functionality of the wetland as a senior independent research project, by comparing it with natural wetlands of similar size and hydrology. This will provide early baseline data in the development of the wetland, and we plan to continue to do periodic assessments, using the same protocols, to track its growth and development.

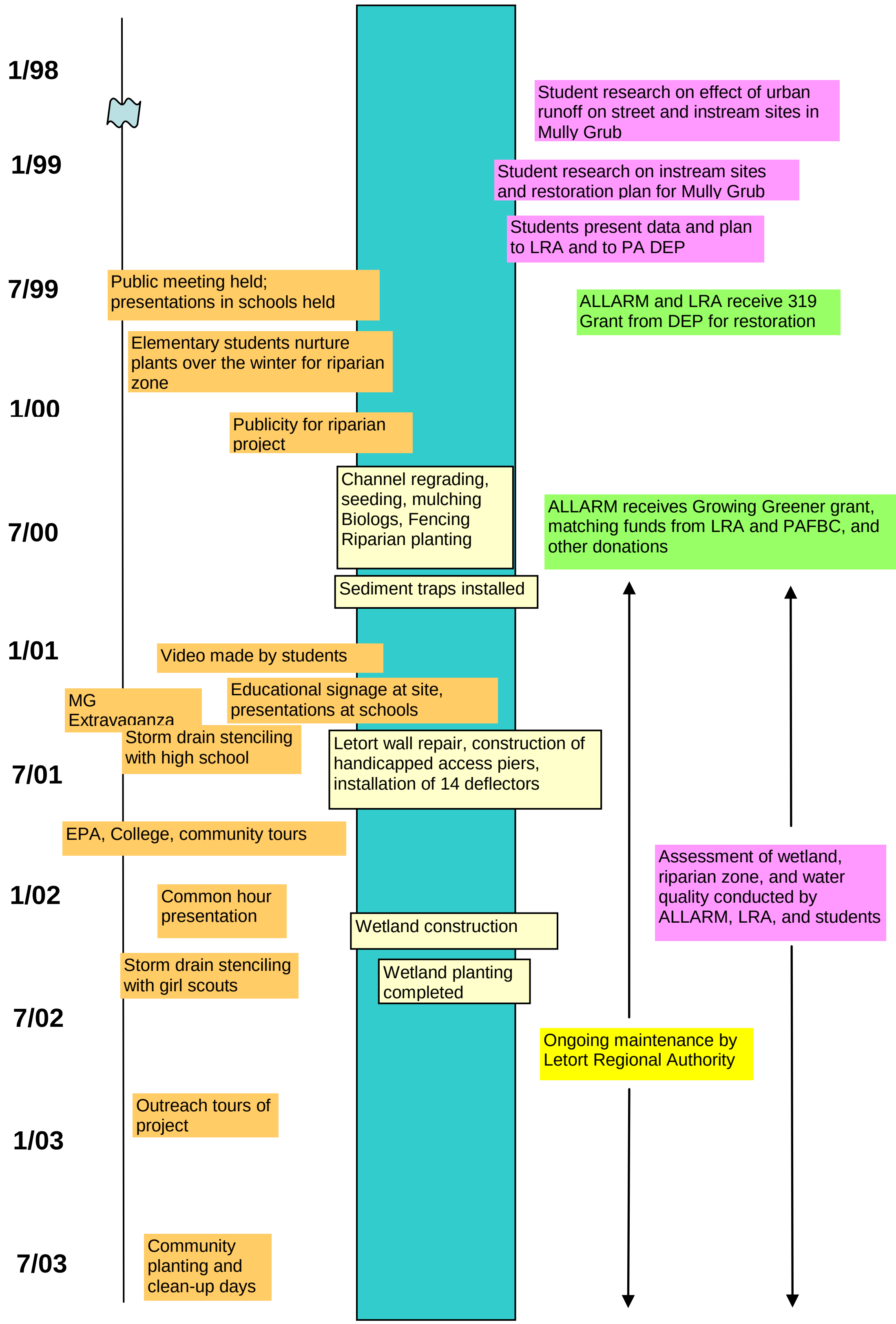


Figure 28. Timeline of major events in the Mully Grub restoration project.

To increase the visual appeal of the site, in order to increase the community's sense of caring, pride, and motivation to maintain the project.

The riparian zone trees have been identified, tagged and measured by students in the Plant Systematics class and in the Introduction to Environmental Science class, and are periodically re-measured by ALLARM student staff to track growth rates and mortality. New plantings at both the wetland and the riparian zone have taken place, to replace dead trees and shrubs in the riparian zone and to add more plants to the area surrounding the wetland.

Plans are also being formulated to formally evaluate the community's response to the project. However, the riparian zone will not provide the aesthetic appeal of a wooded corridor for many years. Even the wetland area, although quite aesthetic now, will not mature for many years. Nonetheless, the interest in the community members in coming to information sessions and clean-up days on the Mully Grub is a qualitative measure of their sense of motivation to maintain the project and their appreciation of its value.

When the project was first installed, there was a great deal of curiosity and interest on the part of passers-by and neighborhood residents. We have also observed and heard anecdotally about increased interaction with the Mully Grub on the part of children whose siblings are playing in the ball fields during community baseball games. We expect that a sense of pride and interest will increase as the flora mature and the habitat returns, so that recreational opportunities also increase. The handicapped access pier is heavily used, both for fishing and for sitting and enjoying being close to the creek. We intend to have Dickinson students develop surveys of use and oral interviews with community members and teachers at the school to assess their reactions to this project in the near future, and several more times in the far future.

To involve the community in the project to minimize the cost, to promote educational awareness, to insure long-term maintenance, assessment, and care, to build a sense of stewardship and ownership of the property, and to build community capacity for future projects.

This goal was clearly met, as the community was involved in this project throughout. All of the partners are locally-based groups – governmental, business, environmental, non-profit and educational. All materials were obtained as locally as possible. The general community was brought into the project through community events such as public meetings, informational sessions, planting events, stream clean-up events, and activities for the children of the community.

Whether or not this community involvement will result in the other objectives of this goal is yet to be determined. When surveys and oral interviews are conducted, as mentioned above, the effect of involving the community will be evaluated.

To provide an environmental laboratory for the local school for continued environmental education of the children.

Local teachers are aware of the project and the opportunity for utilizing the site for field instruction. Once the natural systems are more fully developed, and habitat exists for macroinvertebrates, fish, and amphibians, ALLARM staff will work with teachers to develop meaningful field activities for the children.

To provide a model for other community-based urban restoration/mitigation projects.

ALLARM professional staff and faculty members have presented the Mully Grub project as a model for other urban restoration projects at numerous professional conferences and meetings throughout the nation. Brochures on the project have been widely distributed and plans for an information pamphlet are in place. We have conducted numerous tours for city officials, EPA employees, and DEP staff, and will continue to publicize the project and offer our consultation in the future. We also used the Mully Grub project as a focus of learning activities for a group of visiting Russian scholars and environmental activists.

AFTERWORD

The Value of College/Community Partnerships

One of the cool aspects of working on the Mully Grub project is that you have the opportunity to be immersed in the enthusiasm, passion and drive of community people. Since working with ALLARM, I have been truly inspired to become involved in the future, to commit myself to working towards social change, and to follow in their footsteps. (Allie Still, Dickinson College student, graduated 2002)

There are a number of excellent examples of community-based environmental stewardship projects that involve strong university-community partnerships (Ward 1999). These partnerships between community stakeholders and university faculty hold significant benefits for the institution, the students, and the community (Wilderman 2003).

Benefits to students and the institution

Student participation in the Mully Grub project has involved a variety of tasks, including: 1) the design and implementation of the scientific studies to document the effect of urban runoff on the Mully Grub and the Letort Spring Run, 2) the design of a realistic mitigation project, 3) the engagement of the community in the implementation of the mitigation project, and 4) the design and implementation of assessment protocols.

Engaging students in scientific research that is directly relevant to affected communities enhances undergraduate science curricula. Many college students view undergraduate science education as intellectually challenging, but rather isolated from the engaging social and political dimensions of contemporary human problems. In fact, most students perceive science as the sterile memorization of facts, coupled with white-coat, recipe-driven laboratory analysis. Often students do not discover the practical value of their educations until after they graduate. Doing science within the context of community-based research has the potential to transform this perception of science in the students' minds, and therefore, to encourage more students to choose science as a profession.

Because community science requires a problem-centered approach, multiple disciplines must be brought to bear, as experience has shown that approaching social or environmental problems from traditional academic disciplinary perspectives fails to promote meaningful discourse or solutions. Community science also requires the practical application of concepts and methods learned in the classroom, that is students must "use" their educations to engage in the real world of creative, politicized, and often contentious problem-solving. Therefore, endeavors such as the Mully Grub restoration project enhance interdisciplinarity and provide a range of opportunities for students to make connections between their course work and involvement in the "real" world.

Students who are engaged in producing useful data are confronted with a formidable set of challenges, including: 1) designing a study to inform action with limited resources, 2) deciding how much scientific uncertainty is acceptable in recommending an action plan, and 3) being sensitive to the priorities and needs of the community, a particularly difficult task when the community's interests are diverse and possibly conflicting. These challenges are rarely the focus of traditional science education.

But the benefits to the students of confronting these challenges are well worth the effort. Students who have worked on the Mully Grub project report that they have: 1) discovered the importance of an awareness of the social and cultural context of scientific exploration, 2) encountered new models for active learning among community participants, 3) experienced increased accountability and honesty in their laboratory work, 4) developed an appreciation for the challenges of defining acceptable error and acting in the face of scientific uncertainty, 5) felt an increased motivation for broadening and deepening their knowledge, 6) emerged with a sense of commitment to civic involvement, and 7) gained confidence in their own educations and career paths.

Working with local communities benefits the institution in many ways as well. By making undergraduate science more meaningful, community-based projects clearly promote the college's primary mission of educating students. Dickinson College's involvement in the Mully Grub project and other community-based projects through ALLARM has enhanced the reputation of the College in the greater community, has attracted more students, more grant monies, more alumni contributions, and more media attention, and has established a reputation for Dickinson as a center for high profile community research in the state of PA.

Benefits to the community

College-community collaborative action is of benefit to the community as well. Universities and colleges are centers of intellectual activity, and have the resources necessary to perform research in their areas of specialization. When a community group partners with a university, they benefit from access to these facilities – laboratory equipment, library resources, faculty expertise, and computer hardware and software. The College has the resources to maintain this equipment, and the students, professional staff, and faculty have the know-how to operate it. These are tools that would not be normally available to community groups at low or no cost. In the Mully Grub project, the college provided the expertise at no cost to the community – expertise in the area of scientific research, grant writing, and management and oversight of the entire project. In short, a college/community partnership is of great mutual benefit, and the returns on the investments are felt throughout the institution and the community.

REFERENCES CITED

Adams WJ, RA Kimerle, and JW Barnett, Jr. 1992. Sediment quality and aquatic life assessment. *Environ. Sci. Technol.* 26:1863-1876.

Athanas, C and C Stevenson. 1991 The use of artificial wetlands in treating stormwater runoff. Prepared for the Maryland Sediment and Stormwater Administration. 66 pp.

Barbour, MT, J Gerritsen, BD Snyder, and JB Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C. available on line at http://www.epa.gov/owowwtr1/monitoring/rbp/index.html.

Bilby, RE and GE Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61(5): 1107-1113.

Bohn, BA and JL Kershner 2002. Establishing aquatic restoration priorities using a watershed approach. *Journal of Environmental Management* 64, 355-363.

Booth,D. 1991. Urbanization and the natural drainage system – impacts, solutions and prognoses. *Northwest Environmental Journal* 7(1):93-118.

Buttle, JM and F Su. 1988. Snowmelt runoff in suburban environments. *Nordic Hydrology* 19:19-40.

Cassidy, FG and JH Hall, eds. 1996. Dictionary of American Regional English, Volume III (I-O), The Belknap Press of Harvard University Press. Cambridge, Massachusetts, USA.

Center for Watershed Protection. 2003. Impacts of impervious cover on aquatic systems. Center for Watershed Protection, Ellicott City, Maryland, USA

Chang, G, J Parrish and C Souer. 1990. The first flush of runoff and its effect on control structure design. Environ. Resource Mgt. Div. Dept. of Environ. and Conservation Services, Austin, TX.

Chopyak, J. 2001. Citizen participation and democracy: examples in science and technology. *National Civic Review* 90(4):375-383.

Cole, RH, RE Frederick, RP Healy, and RG Rolan. 1984. Preliminary findings of the priority pollutant monitoring project of the Nationwide Urban Runoff Program. *J. Water Poll. Cont. Fed.* 56 (7): 898-908.

Cook, T, D Drury, R Katznelson, C Lee, P Mangarella, and K Whitman. 1995. Storm water NPDES monitoring in Santa Clara Valley, *Proceedings from Stormwater NPDES Related Monitoring Needs*. Crested Butte, CO. Aug 7-12. 1994.

Dixit, SS, JP Smol, and JC Kingston. 1992. Diatoms: powerful indicators of environmental change, *Environmental Science and Technology* 26 (1): 23-31.

Efroymson, RA, GW Suter II, BE Sample, DS Jones. 1997. Preliminary remediation goals for ecological endpoints. US Department of Energy, Office of Environmental Management. ES/ER/TM-162/R2

Ely, E. (ed) 1999. *The Volunteer Monitor* 11(1), Issue Topic: Restoration, Spring, 1999, available on line at http://www.epa.gov/owow/monitoring/volunteer/issues.htm.

Giere, O. 1993. Meiobenthology: the microscopic fauna in aquatic sediments. Springer-Verlag, Berlin, Germany.

Hanna, GD. 1930. Hydrax, a new mounting medium for diatoms, *Journal of the Royal Microscopical Society*. London, Series 3, 50(4): 424-426.

Heip C, N Smol, and W Hautekiet. 1974. A rapid method of extracting meiobenthic nematodes and copepods from mud and detritus. *Marine Biology* 28: 79-81

Hession, WC. 2001. Riparian forest and urban hydrology influences on stream channel morphology: implications for restoration. *in* D. Phelps and G. Sehlke (eds), *Proceedings of the World Water and Environmental Resources Congress*, May 20-24, 2001, Orlando, Florida, USA.

Higgins, RP and H Thiel. 1988. Introduction to the study of meiofauna. Smithsonian Institution Press, Washington, DC, USA.

Hustedt, F, 1939. Die diatomeenflora des Kustengebietes der Nordsee vom Dollart bis zur Elbemundung, *Abh. Naturwissenschaftlicher Verein zu Bremen*, 31(3):572-677.

Ingersoll, CG, DD MacDonald, N Wang, JL Crane, LJ Field, PS Haverland, NE Kemble, RA Lindskoog, C Severn, and DE Smorong. 2000. Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines, United States Geological Survey final report for the US Environmental Protection Agency, Great Lakes National Program Office, EPA 905/R-00/007.

Ingersoll, CG, DD MacDonald, N Wang, JL Crane, LJ Field, PS Haverland, NE Kemble, RA Lindskoog, C Severn, and DE Smorong. 2001. Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines, *Archives of environmental contamination and toxicology*, 41(1):8-22.

Kauffman, JB, RL Beschta, N Otting, and D Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States, *Fisheries*, 22(5), 12-24.

Krebs, CJ. 1989. Ecological methodology. Harper Collins Publishers, New York, New York. USA.

Leopold, L. 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts, USA.

Manczka, Gary. Pennsylvania Department of Environmental Protection Laboratories, personal communication, 1993.

Nezil-Salvaggio,P, D Cameron, D Rourke, B Hoyt, and B Kooser. 1990. Poison runoff in the Harrisburg region: stemming the flow, the poison runoff index and stormwater solutions. Special report from the Chesapeake Bay Foundation and the Natural Resources Defense Council.

Oberts, GL. 2000. Influence of snowmelt dynamics on stormwater runoff quality, *Watershed Protection Techniques* 1(2): 55-61, reprinted in Schueler, TR and HK Holland, eds. 2000 The Practice of Watershed Protection, Center for Watershed Protection, Ellicott City, Maryland, USA. pp. 22-28.

Palmer, MA and DL Strayer. 1996. Meiofauna, in FR Hauer and GA Lamberti, eds. Methods in Stream Ecology. Academic Press, San Diego, California, USA.

Park, P, M Brydon-Miller, B Hall, and T Jackson (Eds.) 1993. *Voices of change: Participatory research in the United States and Canada*. Westport, CT: Bergin and Garvey.

Patrick, R, MH Hohn, and JH Wallace. 1954. A new method for determining the pattern of the diatom flora, *Notulae Naturae of the Academy of Natural Sciences of Philadelphia* 259, 12 pp.

Patrick, R and CW Reimer. 1966, 1975. The Diatoms of the United States. Volume 1-2. *Monogr. Acad. of Natr. Sci. Phila*. No. 13.

Pennsylvania Code, 2004a. Ch. 16. Water Quality Toxics Management Strategy, available on line at http://www.pacode.com/secure/data/025/chapter16/chap16toc.html#16.24.

Pennsylvania Code, 2004b. Ch. 93. Water Quality Standards, available on line at http://www.pacode.com/secure/data/025/chapter93/chap93toc.html.

Pennsylvania Department of Environmental Protection. 2002. Division of Water Management, Maximum Contaminant Levels, available on line at http://www.dep.state.pa.us/dep/deputate/watermgt/wsm/WSM_DWM/PA-MCLs.pdf.

Pennsylvania Department of Environmental Resources. 1988. Letort Spring Run, Cumberland County, Bureau of Water Quality Management. Harrisburg, Pennsylvania, USA.

Pfankuch, DJ. 1975. Stream reach inventory and channel stability evaluation. USDA Forest Service R1-75-002. Government Printing Office #696-260/200. Washington, D.C., USA. 26 pp.

Pizzuto, J, W Hession, and M McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania, *Geology* 28(1):79-82.

Raloff, J. 1998. Democratizing science. *Science News* 154 (November): 298-300.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado, USA.

Schlekat, C, BL McGee, DM Boward, E Reinharz, DJ Velinsky, and TL Wade. 1994. Biological effects associated with sediment contamination in the Potomac and Anacostia rivers in the Washington, DC area. *Estuaries* 17:334-344.

Schueler, TR. 1994. Review of pollutant removal performance of stormwater ponds and wetlands. Watershed Protection Techniques 1(1): 17-19.

Schueler, TR. 2000. The architecture of urban stream buffers, *in* Schueler and Holland (eds), The practice of watershed protection, Center for Watershed Protection, Ellicott City, Maryland, USA. pp. 225-233.

Schueler, TR and HK Holland. 2000 (eds.) The practice of watershed protection, Center for Watershed Protection, Ellicott City, Maryland, USA. 742 pp.

Sclove, RE, M Scammell, and BHolland. 1998. *Community-Based Research in the United States: An Introductory Reconnaissance, Including Twelve Organizational Case Studies and Comparison with the Dutch Science Shops and the Mainstream American Research System – Executive Summary.* Amherst: The Loka Institute.

Skelly and Loy, Inc. 2000. Letort Spring Run watershed assessment, prepared for Cumberland Valley Chapter of Trout Unlimited, publication #1600164.

Strong, JG. 1867. Map of Carlisle, Penna from actual surveys taken by JG Strong, CE, available at the Cumberland County Historical Society Museum and Hamilton Library, Carlisle, PA.

Sweeney, BW. 1993. Streamside forests and the physical, chemical and trophic characteristics of Piedmont streams in eastern North America. *Wat. Sci.Tech*. 26 (12): 2653-2573.

Thorp, JH and AP Covich, eds. 1991 Ecology and classification of North American freshwater invertebrates. Academic Press. San Diego, California, USA.

Trimble. S. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. *Science* 278:1442-1444.

United States Environmental Protection Agency 1997. Volunteer stream monitoring: a methods manual, Office of Water 4503F, EPA 841-B-97-003, available on line at http://www.epa.gov/owow/monitoring/volunteer/stream/.

Van Dam, H, A Mertens and J Sinkeldam 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology* 28(1):117-133.

Wallis, AD 1996. Toward a paradigm of community-making. *National Civic Review* 85:34-47.

Ward, H. 1999. *Acting locally: concepts and models for service-learning in Environmental Studies*. Washington, DC: American Association for Higher Education.

West, J. 2000. Bioengineering in Four Mile Run, Virginia, *in* Schueler and Holland (eds), The practice of watershed protection, Center for Watershed Protection, Ellicott City, Maryland, USA. pp. 722-724.

Wilderman, CC et al. 1994. A preliminary assessment of the water quality of urban runoff in Carlisle, PA and its effects on the Letort Spring Run. Dickinson College, Environmental Studies Department, July, 1994.

Wilderman, CC et al. 1997. As assessment of stormwater runoff quality in Middlesex Township, Cumberland County, PA, with a comparison of the composition and effects of stormwater runoff from four land uses in the Letort Spring Run Watershed. Dickinson College, Environmental Studies Department, December, 1997.

Wilderman, CC. 1999. "ALLARM: a case study on the power and the challenge of service in undergraduate science education," *in* Harold Ward, ed. Acting locally: concepts and methods for service-learning in environmental studies, The American Association for Higher Education, pp. 179-189.

Wilderman, CC, A Barron and L Imgrund. 2003. "The ALLARM program: growth, change, and lessons learned," *The Volunteer Monitor*, 15(1), pp.1-5.

Wilderman, CC 2003. "Community-College Partnerships: Who Benefits?" *The Volunteer Monitor*, 15(1), p. 4.

Wilderman, CC, A Barron and L Imgrund, in press. "From the Field: A service provider's experience with two operational models for community science," Community-Based Collaboratives Research Consortium Journal, available on line at http://www.cbcrc.org/journal.html