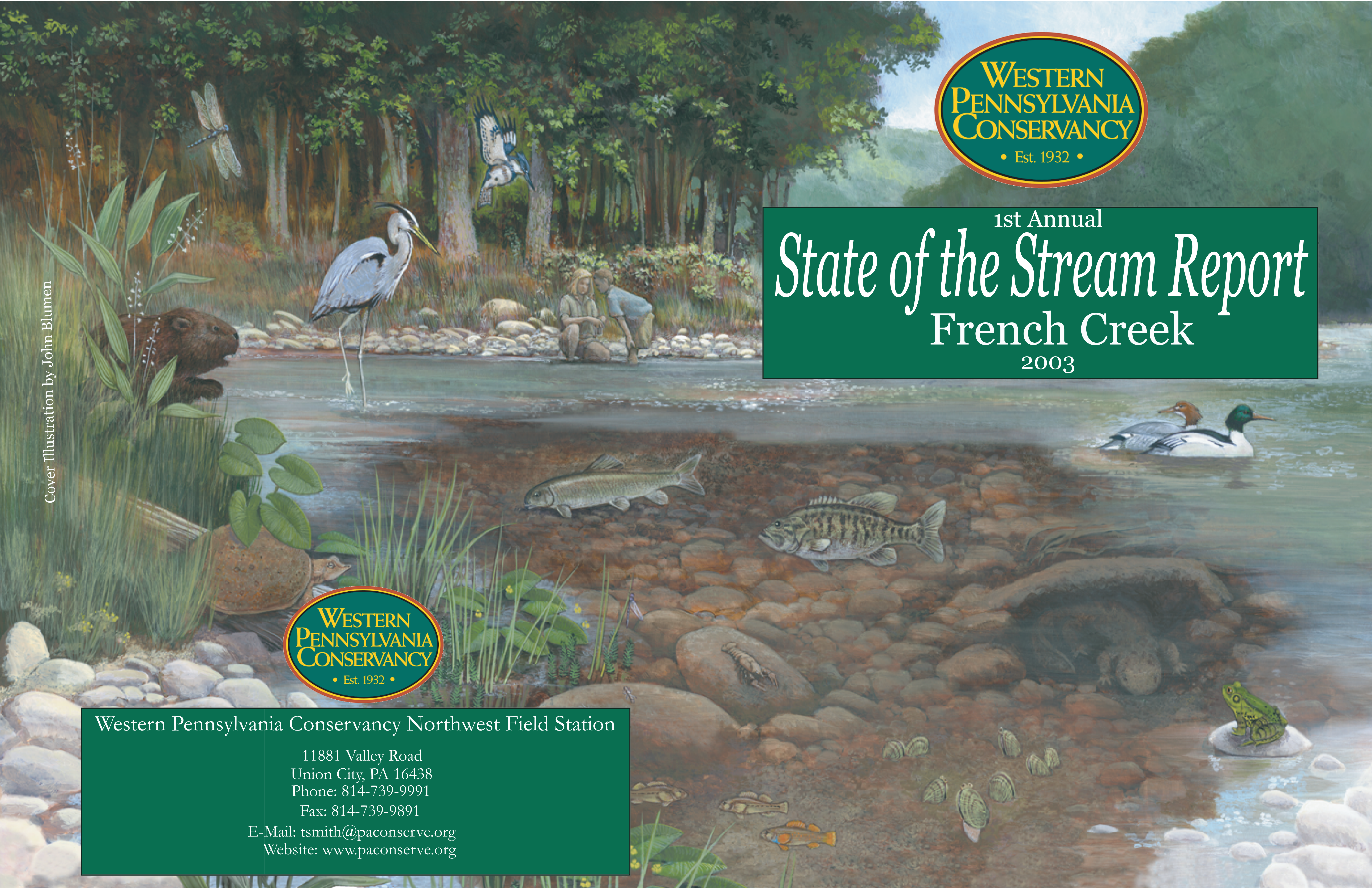

Cover Illustration by John Blumen

WESTERN PENNSYLVANIA CONSERVANCY
• Est. 1932 •

1st Annual

State of the Stream Report
French Creek
2003

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Western Pennsylvania Conservancy Northwest Field Station

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1st Annual

State of the Stream Report
French Creek, Pennsylvania

2003

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Funded in part by
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MISSION

Western Pennsylvania Conservancy's mission is to save the places we care about by connecting people to the natural world.

ACHIEVING OUR MISSION IN FRENCH CREEK

Since the 1950s, Western Pennsylvania Conservancy (WPC) has recognized the uniqueness and need to protect the glacial region of northwest Pennsylvania for future generations to enjoy. Home to significant geological, archaeological, and ecological resources, this region holds treasures found nowhere else in the Commonwealth.

Even in those early days, WPC scientists recognized the significance of the French Creek watershed. This river system held the highest degree of biodiversity found anywhere in the northeast U.S. and became a priority project area for WPC. The first land protection efforts began in the 1960s with acquisition of rare wetland communities that would become a National Natural Landmark, the Wattsburg Fen Natural Area. Scientists from WPC worked with other conservation organizations like The Nature Conservancy to raise awareness of French Creek, an effort that lead to its inclusion in the TNC publication, *Rivers of Life*. WPC continued its scientific research in the French Creek watershed and in 1995, to further accomplish its mission, joined with the Pennsylvania Environmental Council and Allegheny College to form the French Creek Project, a nationally recognized community education and outreach endeavor to further raise awareness of French Creek and connect its watershed residents to this natural treasure.

In 2000, as a way to better engage with French Creek watershed communities and more thoroughly study the creek, WPC established its Northwest Field Station in the watershed. As a partner in the French Creek Project, WPC completed the comprehensive French Creek Watershed Conservation Plan in early 2002. This provided, for the first time, a blueprint for environmental education, conservation, and restoration of French Creek. Today, Western Pennsylvania Conservancy continues its efforts to better understand the processes governing the French Creek watershed and our impacts on water quality, aquatic biodiversity, and human quality of life. We are working with our partners in the French Creek Project, County Conservation Districts, local governments, environmental agencies, and conservation organizations to engage landowners in voluntary, incentive-based conservation practices, and we are striving to ensure important community decisions have sound, scientific data to inform them.

Western Pennsylvania Conservancy and many of our partners, including French Creek Project, The Nature Conservancy, County Conservation Districts, USDA Natural Resource Conservation Service, Conneaut Lake/French Creek Valley Conservancy and others are committed to protecting the rural, agricultural heritage of French Creek communities. This is evident in the hundreds of thousands of dollars raised by these organizations to assist farmers to implement Best Management Practices. Furthermore, WPC and our partners have worked diligently to expand programs like the Conservation Reserve and Enhancement Program (CREP), Growing Greener, and landowner incentive programs that could mean millions of dollars in support for French Creek farmers. Projects like this French Creek watershed assessment are crucial to understanding human impacts to our aquatic resources. This report will be a useful tool in leveraging much of the funding needed to work cooperatively with French Creek's agricultural community to protect French Creek's amazing natural resources and its watershed residents' rural quality of life.

The ***2003 State of the Stream Report on French Creek*** is the first of an annual report we plan to make to the communities of French Creek. We hope information such as this can help us to achieve our mission of connecting people to this special place. As an annual report, WPC pledges to continue engaging our partners in conservation and updating the public on the health of this watershed. In French Creek, we are striving to protect this place we care about by connecting people to its natural wonders.

ACKNOWLEDGEMENTS

The French Creek Watershed Assessment and resulting State of the Stream Report were funded in part by a Growing Greener Grant provided by the Pennsylvania Department of Environmental Protection. The Sansom-Eligator Foundation, Pennsylvania State Wildlife Grant Program, and Western Pennsylvania Conservancy provided additional funding. Dr. Eric Straffin, Edinboro University of Pennsylvania, Department of Geosciences, provided expertise and in-kind match in the development of a pilot study on French Creek's geomorphology as part of this watershed assessment (see Appendix A).

Western Pennsylvania Conservancy would like to thank staff from our partners at French Creek Project, The Nature Conservancy, Venango and Crawford County Conservation Districts, and the Pennsylvania Department of Environmental Protection who provided input on sampling design, assisted with rain or water sample collection, or assisted in any of the various fieldwork components. Also important to the success of this project were many competent student interns and volunteers from local universities and the Student Conservation Association. Annie Young-Mathews, Erica Maynard, Amy Bush, Chris Larson, Curtis Stumpf, and Dave Homans provided crucial assistance in the office, field, and laboratory.

Western Pennsylvania Conservancy would like to extend a special thank you to the volunteer water quality monitors from the French Creek Pennsylvania Senior Environmental Corps (PASEC) in Crawford and Venango counties. These dedicated individuals met with WPC staff prior to spring rain sampling and agreed to assist with water sample collection. This required expert planning and coordination of several teams, as well as a little help from Mother Nature. On April 14th, 2002, these volunteers received the last minute call that weather conditions were right and sampling needed to happen. Along with WPC staff, these volunteers visited and sampled 105 sites throughout the French Creek watershed during a 12-hour period in heavy rains. Without the help of these volunteers, this project could not have succeeded and WPC is proud to partner with individuals so dedicated to conservation in French Creek.

Todd Sampsell and Tamara Smith
Northwest Conservation Programs
Western Pennsylvania Conservancy
February 2004

The views expressed herein are those of the authors and do not necessarily reflect the views of the Pennsylvania Department of Environmental Protection.

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INTRODUCTION

French Creek, originating in western New York and flowing 117 miles to its confluence with the Allegheny River at Franklin, Pennsylvania, is perhaps the most ecologically significant waterway in the state, containing more species of fish and freshwater mussels (Unionidae) than any other similar sized stream in the northeast United States. Over 80 species of fish and 27 native species of freshwater mussels are found in the watershed along with various other wildlife and plant species.

Two of the mussels found in French Creek are presently listed as Endangered under the U.S. Endangered Species Act, the northern riffleshell (*Epioblasma torulosa rangiana*) and the clubshell (*Pleurobema clava*). Thirteen other mussel species are considered rare, threatened, or endangered in Pennsylvania. Threatened or endangered fish include several madtom and lamprey species, as well as eight of the 15 species of darters found in the French Creek watershed.

There are a number of activities in the French Creek watershed such as agriculture, logging, mineral extraction, and development that may jeopardize water quality. Not only are these potential threats to aquatic organisms, but impacts from these activities may ultimately jeopardize the quality of life for watershed residents.

In this study, chemical, physical, and biological stream conditions were assessed throughout the watershed. It was our goal to identify potential threats and to be able to prioritize recommendations for restoration, maintenance, and protection of aquatic resources in the French Creek watershed. In doing so, the Western Pennsylvania Conservancy (WPC) and our partners can more effectively work in cooperation with landowners to avoid more stringent regulations on water quality impacts.

Study Location

French Creek is part of the Allegheny River watershed and therefore contributes to the Ohio River, the Mississippi River, and ultimately the Gulf of Mexico. The entire French Creek watershed covers an area of approximately 1235 square miles (790,400 acres). Approximately 93% of the watershed is within Pennsylvania, and the remaining 7% is made up of headwater streams in New York. The headwaters of the West Branch of French Creek and the French Creek main-stem form in Chautauqua County, New York and flow southwest to their confluence in Erie County, Pennsylvania. The South Branch of French Creek originates near Corry in Erie County and flows west to its confluence with French Creek west of Union City in Erie County. French Creek flows south through Crawford County, the northeast corner of Mercer County, and finally into Venango County where it flows southeast to its confluence with the Allegheny River at Franklin, Pennsylvania (Figure 1).

The French Creek watershed is mostly rural with only a few urban areas. The watershed is home to approximately 116,000 people, with the largest city being Meadville, PA (2000 Census). Although the landscape has various land uses, most can be categorized as either agricultural or forested (Figure 2).

Monitoring Design and Rationale

Sub-Basin Approach

The French Creek watershed can be divided into 11 major sub-basins with drainage areas greater than 50 square miles (Table 1, Figure 3), including the main-stem sub-basin. Sub-basins provide a useful way to visualize entire watersheds in smaller, more manageable units. These sub-basins vary in land-use, geology, etc. Species distribution and threats to natural resources may differ significantly between sub-basins as well. Therefore, it is likely that the approach for natural resource restoration, maintenance, and protection will be different for each sub-basin. Because of these reasons, this study employed a sub-basin approach as a way to target problem areas in the French Creek watershed.

In this study, we attempt to prioritize sub-basins based on their impacts to the main-stem river. To do this, we summarized physical habitat, land-use, water quality, and macroinvertebrate data for each sub-basin.

Macroinvertebrates

Evaluation of macroinvertebrate communities is a critical component in the biotic evaluation of water quality. Since stream water is constantly moving, physical and chemical measurements made at a certain point in time may not show signs of pollutants that have previously moved down-stream of the sample site. Because stream macroinvertebrates are less mobile than fish and have a 1+-year life span, they can serve as natural, continuous water quality monitors. Many macroinvertebrates are sensitive to long-term, low-level stress and/or pulsed, highly concentrated discharges of water pollutants. Because of these qualities, many environmental monitoring agencies employ macroinvertebrates to assess biotic integrity of stream ecosystems (EPA 1999). Several metrics for evaluating benthic macroinvertebrate data were utilized in this study; including taxa richness, taxa composition, and tolerance indices.

Richness and composition metrics reflect the diversity of the assemblage, which reflects the amount of food, habitat and niche space available to propagate many species. Taxa richness is the total number of distinct taxa within a site. EPT taxa richness is the total number of distinct taxa within the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies). Composition metrics were also calculated, including the percentages of EPT taxa, Ephemeroptera, Plecoptera, Tricoptera, Diptera, and Chironomidae. For the orders Ephemeroptera, Plecoptera and Tricoptera, the expected response to increasing disturbance is a decrease in number of taxa and decrease in percent composition. EPT taxa are a good measure of stream degradation, as they are generally considered more sensitive to disturbance than the other macroinvertebrate orders. Chironomidae and other Diptera are expected to decrease in number of taxa, but to increase percent composition with increasing perturbation (EPA 1999, Barbour et al. 1996).

Tolerance indices reflect on the amount and/or type of pollution in the system. We utilized the Hilsenhoff Biotic Index (HBI), where each macroinvertebrate family is assigned a tolerance value based on tolerance to organic pollution (Hilsenhoff 1988). The tolerance values range from 0-10; the lower scores signify organisms that are more

Figure 1: Location of the French Creek watershed

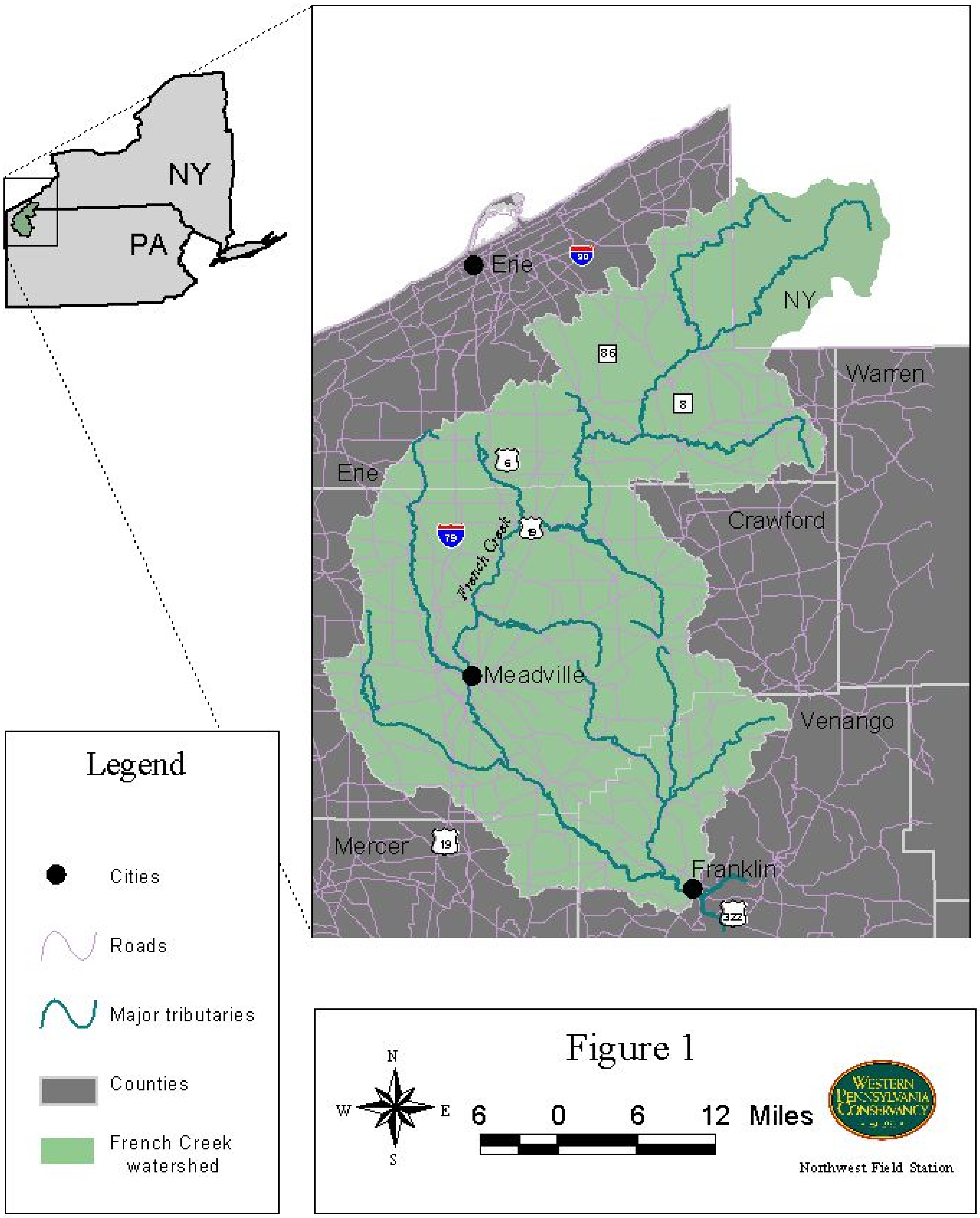


Figure 2: Land-use in the French Creek watershed

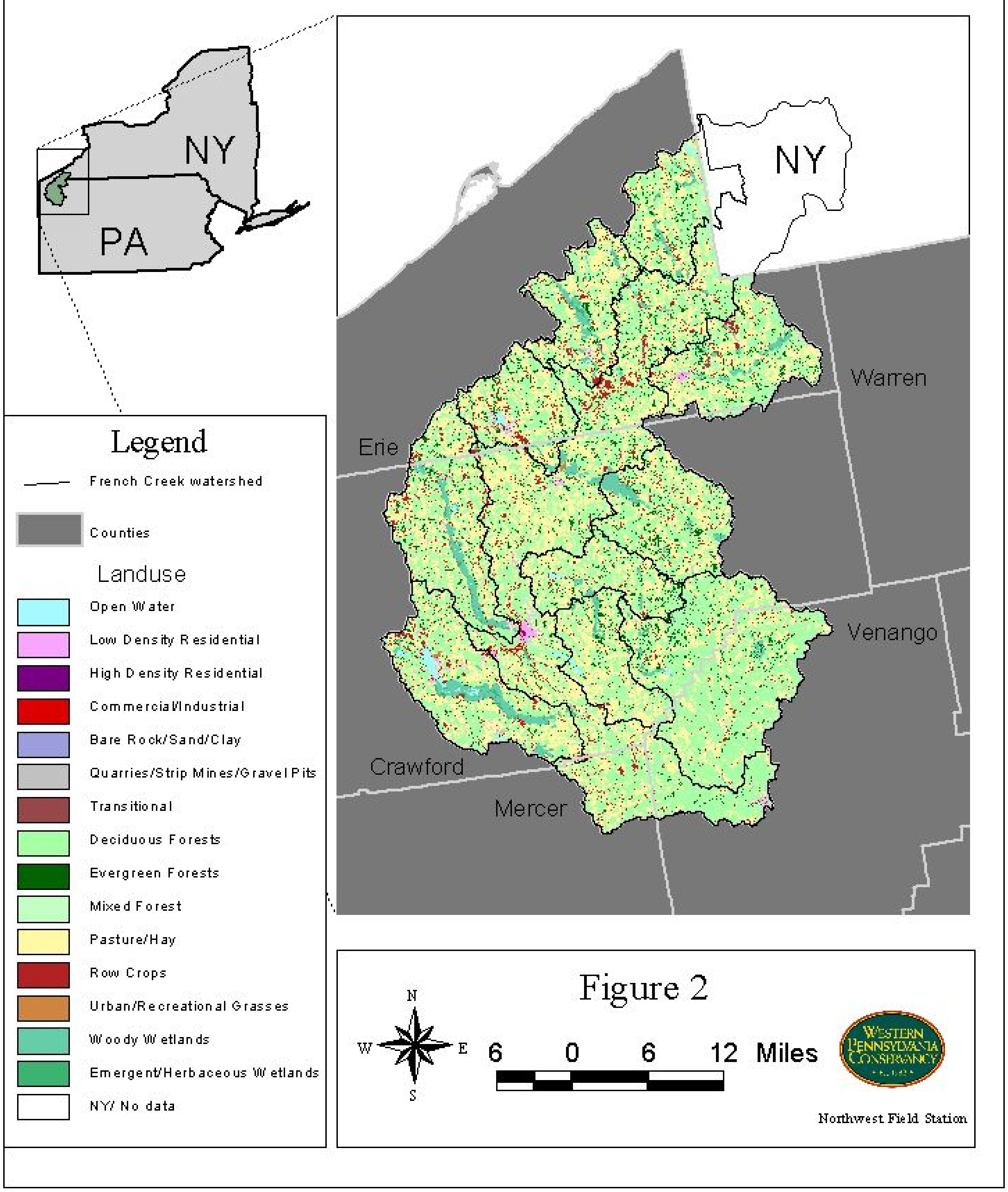


Table 1: Major sub-basins (>50 mi^2) in order from the upstream most to the downstream most confluence with the main stem of French Creek, with description of their confluence location. Included is the total area in acres and area defined as forested and agricultural land. Similar description of the main-stem sub-basin is also included.

Sub-Basin Name	Area (acres)	Agriculture (acres)	Forest (acres)	Confluence Location
West Branch French Creek	34,840	12,694	19,863	Originates in Chautauqua County, New York and joins the main branch of French Creek at Wattsburg, Erie County, PA
South Branch French Creek	52,799	20,778	28,942	Originates near Corry, Erie County, and joins French Creek west of Union City, PA
Le Boeuf Creek	40,634	18,172	18,522	Flows through Waterford, drains Lake Le Boeuf, and joins French Creek near the village of Indian Head, PA
Muddy Creek	48,670	18,085	27,460	Flows through the Seneca Division of the Erie National Wildlife Refuge and joins French Creek near the village of Miller's Station, Crawford County, PA.
Conneauttee Creek	35,351	15,928	17,509	Enters and drains Edinboro Lake, flows through Edinboro, Erie County, and joins French Creek near Cambridge Springs, Crawford County, PA.
Woodcock Creek	32,606	12,830	18,548	Dammed by the United States Army Corps of Engineers (USACE) to form Woodcock Creek Lake, joins French Creek near Saegertown, PA.
Cussewago Creek	62,558	24,168	31,184	Joins French Creek at Meadville, PA.
Conneaut Outlet	64,518	24,249	29,794	Drains Conneaut Lake and joins French Creek south of Meadville, PA.
Little Sugar Creek	33,791	15,107	17,329	Joins French Creek at Cochranton, PA.
Sugar Creek	107,410	29,205	76,243	Joins French Creek at the village of Sugarcreek, Venango County, four miles upstream from the mouth of French Creek at Franklin, PA.
French Creek main	207,732	82,610	116,884	Starting at NY border and ending at the mouth of French Creek at Franklin, PA.

sensitive to organic pollution than higher rated organisms. Thus, a low HBI score indicates better stream conditions than a high score. The HBI is the average tolerance value of all the individual organisms within the sample weighted by the abundance of each family. We assigned tolerance values according to those the Pennsylvania Department of Environmental Protection generated for their Unassessed Waters Program (PADEP 1999). Additional values came from EPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (1999).

Macroinvertebrate community structure was determined by sampling 49 randomly selected stream sites from locations within the French Creek watershed (Figure 3). Three to five sites were sampled in each of the 10 major sub-basins and 13 sites were sampled in the main-stem sub-basin. The macroinvertebrate community was sampled and evaluated using metrics and procedures modified from EPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (1999). Sampling was standardized to 1-minute kicks with a standard D-frame net for 5 sub-samples within each site, which were pooled together for site totals. Different habitat types were sampled in approximate proportion to their surface area in the study reach. Collected macroinvertebrates were placed in 75% ethanol for transport to the lab where they were transferred to 95% ethanol and identified to order level. Macroinvertebrate data were also summarized for each sub-basin and analyzed with their associated water quality, land-use, and physical habitat parameters. To account for varying life stages, macroinvertebrates should ideally be sampled within the same season. When interpreting the following data, one should note that 32 sites were sampled in the spring and the remaining 17 were sampled in the fall of 2002.

A sub-set of macroinvertebrates from 19 random samples were identified to genus level and examined in further detail. All of the samples used in the genus level analyses were taken between 8-May and 23-May 2002.

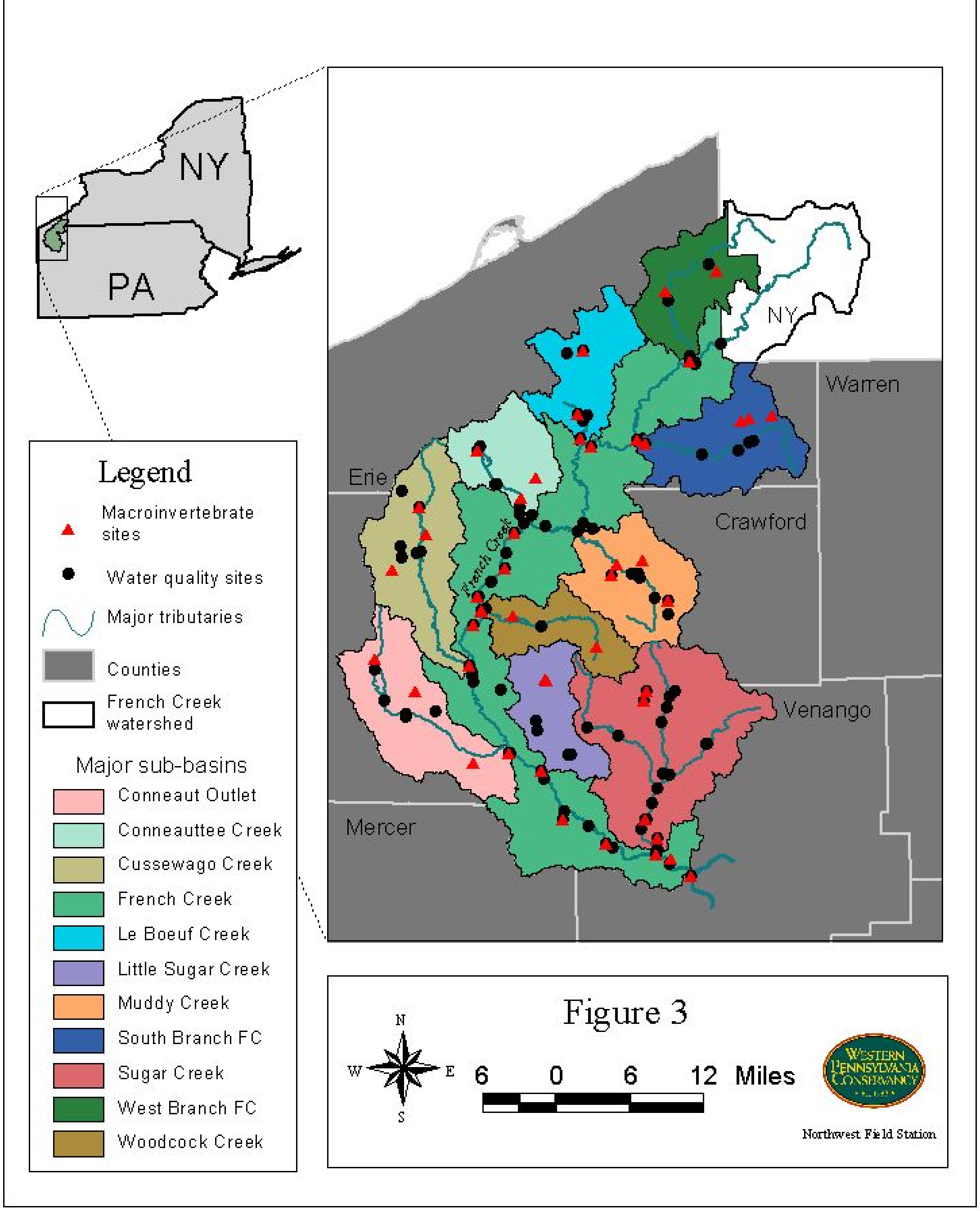
We calculated percent EPT taxa and percent Diptera to evaluate macroinvertebrate communities at all 49 sites. At the 19 sites where generic level data was available, we calculated Ephemeroptera, Plecoptera, Tricoptera and total EPT taxa richness at the family and generic levels. Percentages of Ephemeroptera, Plecoptera, Tricoptera, Diptera, and Chironomidae were calculated for each of the 19 sites. HBI was also calculated for these sites.

Water quality

Macroinvertebrate community analysis alone cannot ascertain exactly the type of pollutant entering stream ecosystems. Therefore, other types of analytical procedures, such as water quality testing, are necessary to complete the picture. Because the French Creek watershed is a highly agricultural area, we suspect nutrient loading and sedimentation as potential threats to aquatic communities, particularly freshwater mussels and darters. Sewage treatment plants, urban runoff, industrial discharge, and other pollution sources in developed areas are also potential areas of concern. Water quality analysis is the first step to develop a nutrient budget for French Creek and would allow for a more efficient approach to the implementation of BMPs and riparian buffer restoration to combat nutrient runoff and loading of groundwater (French Creek Watershed Conservation Plan 2002).

Water quality was assessed at 106 sites in the French Creek watershed using both

Figure 3: Sub-basin delineation and study sites in the French Creek watershed



field and laboratory analyses (Figure 3). Field measurements were measured with a YSI 600 water quality meter and included temperature, conductivity, specific conductance, dissolved oxygen percentage, dissolved oxygen concentration, salinity, and pH. Water samples were collected at each of the sites and sent to Microbac Laboratories, Inc. (Erie, PA) for chemical analyses. These water samples were tested for concentrations of nitrogen, phosphorus, total dissolved solids, suspended solids, ammonia, kjeldahl nitrogen and biological oxygen demand.

The above field parameters and water quality samples were taken at each site during three time periods representing varying water level stages; during summer base flow, after a summer rain event and after a spring rain event. With the help of numerous volunteers stationed throughout the watershed, sampling during rain events occurred within a 12-hour time span to minimize temporal variance. We sampled while water levels were rising on the tributaries and main-stem, as verified by USGS gauging stations. We were only able to sample 28 of the 106 sites during the summer rain event.

For each sampling period, the mean values of water quality parameters for each sub-basin in the French Creek watershed were calculated. We used analysis of variance techniques to determine the significance of differences in water quality parameters between sub-basins. Regression and correlation analyses were used to determine relationships of water quality parameters with habitat, land-use, and macroinvertebrate data.

Water velocities and wetted widths were measured at 12 of the 106 sites during the spring rain event, 26 sites during base flow, and 11 sites during the summer rain event to calculate discharge, which allowed us to compute nutrient loading rates. We expected nutrient loading rates to be highest in the spring, revealing the effects of physical and chemical alteration from farming practices. High loading rates during the summer rain event would suggest additional sources, such as airborne pollutants.

At sites where discharges were calculated, nutrient concentration values were converted into nutrient loading rates. Loading rates will help determine the amount of nutrients each sub-basin (or site) is contributing to the main-stem of French Creek (and eventually the Allegheny and beyond). We compared the loading rates for sites at each sampling period to determine the timing and possible causes of high loading. We used regression analyses to model loading rates and to determine which sites fall out of expected patterns within the system.

In addition to in-stream water sampling, we collected rain samples at three sites during the spring rain event; Lake Pleasant, Meadville and Franklin. These sites represent the northern, middle, and southern regions of the watershed respectively. During the summer rain event we collected rain only from the northernmost site, Lake Pleasant. These rain samples were tested for concentrations of nitrogen, phosphorus, ammonia, organic nitrogen, and kjeldahl nitrogen.

Habitat Evaluations

In-stream and riparian habitat at each macroinvertebrate site were evaluated using DEP's modified EPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (1999). Habitat/riparian evaluations were divided into two parts; the first dealing more with in-stream habitat and the second focusing on riparian conditions. Habitat/riparian score 1 equals the total number of points given from visual evaluations of in-stream cover, epifaunal substrate, embeddedness, velocity/depth regimes, channel alteration and sediment deposition. Habitat/riparian score 2 equals the total number of points given from visual estimations of riffle frequency, channel flow status, bank condition, vegetative protection on bank, grazing/other disruptive pressure, and riparian vegetative zone width. All parameters were rated on a numerical scale, ranging from 0-20, and increase as habitat quality increases. So, 120 is the highest possible for both scores 1 and 2. Scores 1 and 2 added together is denoted as the total habitat/riparian score. Habitat/riparian scores were summarized for each site and sub-basin and compared to associated macroinvertebrate communities, water quality, and land-use data.

Land-use

We utilized GIS spatial data to locate land-use factors physically impacting aquatic communities in French Creek. We were particularly interested in the percentage of land used for agricultural purposes versus forested land, and how this may impact water quality in the watershed. For this analysis, the French Creek watershed was delineated into 11 major sub-basins (Figure 3) and percent agriculture and forest was calculated for each sub-basin (Figure 4). We defined agricultural land as that covered by row crops or pasture/hay. Forested land included mixed forest, deciduous forest, evergreen forest and transitional forests. We used regression and correlation analyses to compare percentages of agricultural and forested land for each sub-basin to macroinvertebrate, habitat, and water quality data.

Main-stem habitat evaluation

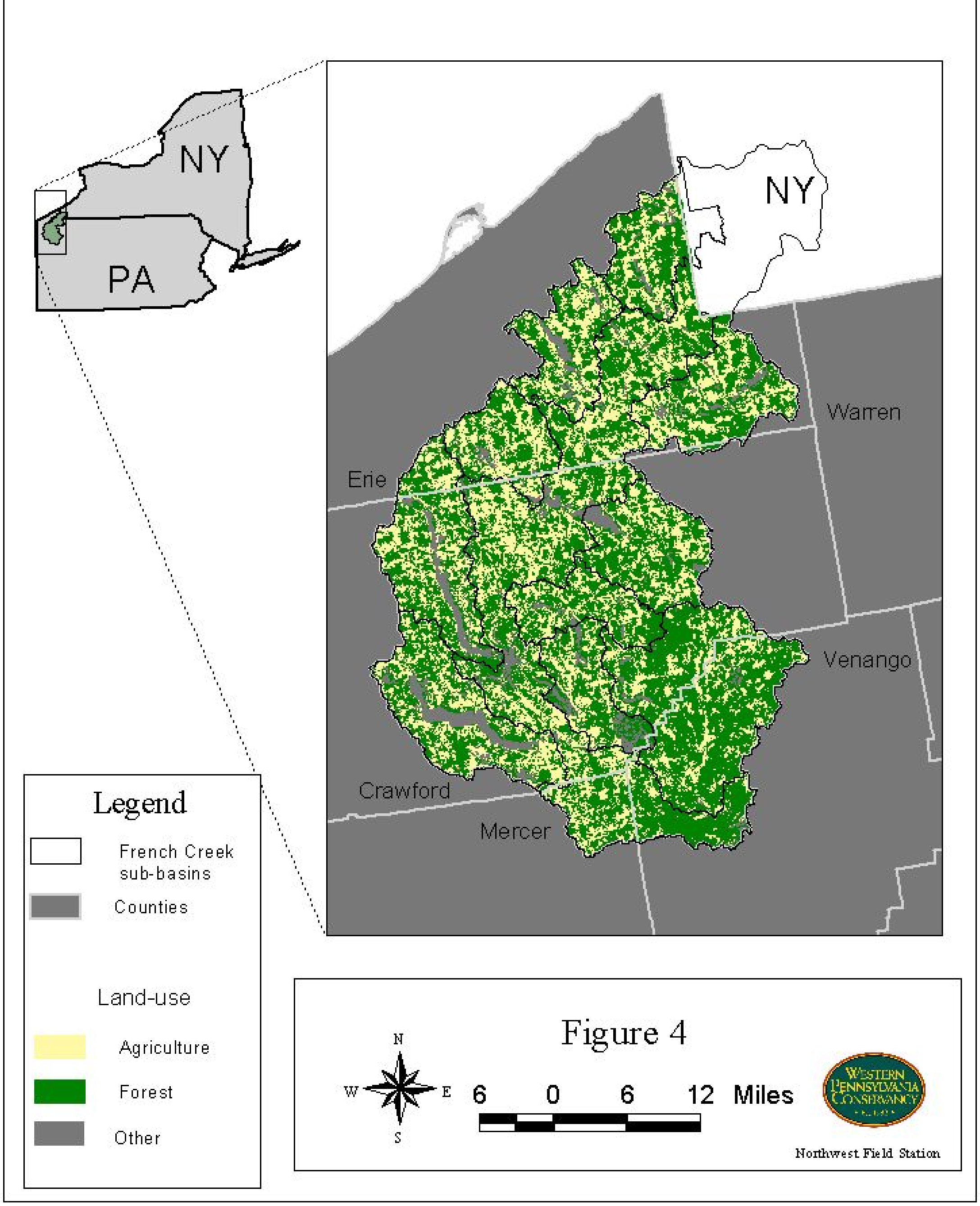
Almost the entire length of the Pennsylvania portion of French Creek main-stem was mapped using GPS and GIS technology. Stream reaches were measured and categorized into one of 3 flow regimes; pool, run, riffle, or a combination of these regimes. Visual estimations of substrate types were noted for each reach. Gravel sized substrate in riffle and run flow regimes make up what is believed to be essential habitat to many freshwater mussels and fish of special concern in this watershed.

Additional features were mapped along the main-stem such as locations of discharge pipes into French Creek. Locations of muskrat middens, piles of empty freshwater mussel shells deposited by muskrats, were mapped as well.

At sites beginning below the USACE Union City Dam, observers stopped at approximate 0.5-1.0 mile intervals to perform in-depth riparian assessments developed at Pennsylvania State University (Schnier 2002, np). At these 55 sites, riparian area was assessed using visual estimation of the following: riparian buffer width, riparian vegetation type, riparian vegetation thickness, bank vegetation type, bank vegetation thickness, bank stability, water pathways, channel modification, canopy cover, in-stream cover, embeddedness, aquatic vegetation, and land-use. Total scores were converted to percentage out of a possible 100 percent. We analyzed these riparian assessments to make generalizations for the upper, middle, and lower portions of the main-stem channel.

A portion of French Creek, south of the Union City dam, was studied in further detail, to document the basic physical parameters of the stream including the geomorphology, sedimentology, and hydrology of the channel (Straffin 2003, Appendix A). This study provides a model that may be used as a reference for stream hydrologic monitoring efforts in the future.

Figure 4: Agricultural and forested land in the French Creek watershed



MACROINVERTEBRATES

Analysis and Results

Between sub-basins

Finding differences in macroinvertebrate composition between sub-basins will give us an idea if aquatic communities vary across the watershed. This information can be further examined to find out exactly where problem areas exist and how aquatic communities respond to varying water quality and habitat parameters.

To assess the significance of differences in taxa richness and macroinvertebrate composition measures between sub-basins, we used one-way ANOVAs (Analysis of Variance). Significance was assessed at the $\alpha = 0.05$ level. We found no significant differences between sub-basins for % Diptera (F-value= 1.89, p-value = 0.076), but we did find significant differences between sub-basins for percent EPT (F-value= 2.59, p-value = 0.017).

Significant differences between sub-basins were further assessed by comparing each sub-basin to the entire watershed. We did this to determine if any of the sub-basins stood out as potential problem areas compared to what was typical of the watershed. To test if sub-basin means were different from the overall mean, we compared 95% confidence intervals. First, we calculated the overall mean and 95% confidence interval (denoted by two numbers in parenthesis following the mean) for each parameter using all the data for the entire watershed. If the sub-basin mean did not fall within the overall 95% confidence interval, there is significant difference at the $\alpha = 0.05$ level (Table 2). These analyses give us a good picture of which sub-basins are outliers compared to what was typically observed for the whole watershed.

Table 2: Mean percent EPT and percent Diptera values for each sub-basin. These values were compared to the mean and 95% confidence intervals for the entire French Creek watershed. Bolded values are significantly different from the overall mean at the $\alpha = 0.05$ significance level.

Sub-basin	% EPT	% Diptera
Conneaut Outlet	**77**	**11**
Conneauttee Creek	**33**	21
Cussewago Creek	52	**28**
French Creek	67	**10**
Le Boeuf Creek	**28**	**50**
Little Sugar Creek	**37**	**26**
Muddy Creek	**65**	17
South Branch French Creek	**70**	17
Sugar Creek	**70**	17
West Branch French Creek	**25**	**15**
Woodcock Creek	54	**26**
French Creek Watershed mean	55	20
French Creek Watershed 95% CI	(48, 61)	(16,24)

The mean % EPT taxa across all sites was 55% (49, 61) and the mean % Diptera was 20% (16,24). West Branch French Creek, Le Boeuf Creek, Conneauttee Creek, and Little Sugar Creek sub-basins all fell significantly below the overall mean EPT percentage. Conneaut Outlet had the highest mean percent EPT (77%) of all the sub-basins followed by South Branch (70%), Sugar Creek (70%), and Muddy Creek (65%). Sub-basins with significantly higher percent Diptera than the watershed mean were Le Boeuf Creek, Cussewago, Woodcock, and Little Sugar Creek.

Microhabitat sampling

Most of our sampling was done in riffles (n_{riffle}=104) and runs (n_{run}=76), and less in near bank vegetation (n_{veg}=28), woody debris (n_{wood}=25) and pools (n_{pool}=12). We ran a one-way ANOVA to determine if there was a significant difference of percent EPT between microhabitat types. We found a significant difference in percent EPT for different sampled microhabitats (F-value = 4.71, p-value = 0.001). Mean % EPT for each microhabitat sampled were 43.7% (35.5, 51.9) in near bank vegetation, 35.0% (17.3, 52.6) in pools, 59.2% in riffles (54.4, 64.0), 50.3 % (44.5,56.1) in run and 45.7%(33.3, 58.1) in woody debris. We ran a similar one-way ANOVA to determine if there was a significant difference of percent Diptera between microhabitat types and found no significant differences (F-value =1.94, p-value = 0.104).

Sub-sampled sites

Results from the 19 sub-sampled sites for genus level macroinvertebrate identification are shown in Table 3. The mean taxa richness at the family level is 17 (15.6, 18.3) and 21(19.3, 22.8) at the genus level. Since the number of macroinvertebrates identified at the 19 sites ranged from 82 to 240, we wanted to ensure there were no correlations between the numbers identified and the richness measures. Results of regression analysis show no significant relationships between the number of macroinvertebrates identified to the genus family richness (p-value = 0.268).

We used ANOVAs to assess the differences in taxa richness and macroinvertebrate composition measures between the 19 sub-sampled sites. Results are reported in Table 4. We found significant differences between sites for percent Plecoptera, percent Tricoptera on order level data. For genus level data, there were significant differences between sites for number of Plecoptera and number of EPT taxa.

We found significant differences between sites for percent Plecoptera, percent Tricoptera on order level data. Sites with particularly low percent Plecoptera are sites 33 and 40 in French Creek (confluences with West Branch French Creek and Le Boeuf Creek), mouth of Little Sugar Creek (site 41), Trout Run (site 23) on Le Boeuf Creek, mouth of Cussewago Creek (site 47), and site 49 on Conneauttee Creek. Sites with particularly low percent Tricoptera are Trout Run and East Branch Le Boeuf Creek (sites 23 and 24) in Le Boeuf Creek, and Gravel Run (site 18) in French Creek.

Table 3: Summary of macroinvertebrate data that was identified to genus level (19sites). Subsets of 82-212 individuals from each sample were identified. G=generic level.

Macro Site Number	Site Name	Sub-Basin	Total Number ID'd	HBI	Taxa Richness-G	% Ephemeroptera	% Plecoptera	% Tricoptera	% EPT	% Diptera	% Chironomidae	No. Ephemeroptera Taxa-G	No. Plecoptera Taxa-G	No. Tricoptera Taxa-G	No. EPT Taxa-G
1	West Branch Sugar	Sugar	204	3.68	26	0.26	0.37	0.10	0.72	0.21	0.12	7	8	8	23
6	East Branch Muddy	Muddy	203	4.64	23	0.23	0.20	0.12	0.54	0.24	0.20	8	5	6	19
8	Beatty Run	Sugar	212	4.04	24	0.39	0.17	0.11	0.61	0.15	0.12	10	4	5	19
10	Patchell Run	French Creek	82	3.70	16	0.57	0.04	0.26	0.8	0.07	0.06	6	2	4	12
12	North Deer Creek	French Creek	184	4.26	28	0.42	0.19	0.07	0.66	0.25	0.14	9	2	10	21
15	Inlet Run	Conneaut	207	3.01	16	0.20	0.56	0.13	0.76	0.06	0.04	9	3	3	15
18	Gravel Run	French Creek	203	6.29	21	0.26	0.03	0.03	0.32	0.31	0.21	7	3	3	13
20	Little Conneauttee	Conneauttee	202	5.41	21	0.39	0.11	0.05	0.41	0.19	0.19	12	4	3	19
23	Trout Run	Le Boeuf	204	8.55	12	0.02	0.02	0	0.06	0.72	0.71	3	1	1	5
24	East Branch Le Boeuf	Le Boeuf	199	7.64	20	0.11	0.08	0.03	0.17	0.55	0.54	4	3	4	11
25	West Branch FC	West Branch	199	5.92	18	0.17	0.02	0.09	0.16	0.19	0.19	5	1	4	10
29	Woodcock Creek	Woodcock	203	6.50	21	0.17	0.07	0.09	0.22	0.34	0.32	6	4	3	13
30	Slaughter Run	South Branch	228	4.98	21	0.46	0.03	0.06	0.50	0.13	0.12	11	1	4	16
33	French Creek at West Branch	French Creek	211	4.69	24	0.16	0.01	0.17	0.33	0.06	0.03	8	3	6	17
36	Mouth French Creek	French Creek	175	4.47	21	0.48	0.04	0.22	0.67	0.13	0.13	10	2	6	18
40	French Creek at Le Boeuf	French Creek	240	4.18	21	0.48	0	0.06	0.55	0.04	0.03	7	1	5	13
41	Mouth Little Sugar	Little Sugar	221	4.32	22	0.49	0	0.29	0.79	0.07	0.06	6	1	4	11
47	Mouth Cussewago	Cussewago	201	5.89	21	0.41	0.01	0.36	0.79	0.1	0.09	4	1	6	11
49	Conneauttee	Conneauttee	213	5.41	24	0.03	0.01	0.26	0.35	0.15	0.09	4	2	5	11

Table 4: Results of ANOVAs comparing site means of macroinvertebrate metrics. Significant (p-value <0.05) results are in bold type.

Parameter	F value	p-value
% EPT	.207	0.655
% Diptera	1.89	0.076
HBI	1.10	0.308
Genus Taxa Richness	0.04	0.850
% Ephemeroptera	0.00	0.965
% Plecoptera	**10.60**	**0.005**
% Tricoptera	**4.85**	**0.042**
% Chironomidae	0.21	0.602
No. Plecoptera-Genus Level	**12.70**	**0.002**
No. Ephemeroptera–Genus Level	1.99	0.175
No. Tricoptera –Genus Level	1.99	0.176
No. EPT –Genus Level	**6.06**	**0.025**

For genus level data, there were significant differences between sites for number of Plecoptera and number of EPT taxa. West Branch Sugar Creek (site 1) in Sugar Creek sub-basin had particularly high number of Plecoptera taxa compared to the other sites. The number of EPT taxa was particularly low at Trout Run (site 23) on Le Boeuf Creek and high at West Branch Sugar Creek. Trout Run (site 23) on Le Boeuf Creek has the lowest number of EPT taxa (5).

The mean HBI score for the 19 sites was 5.14 (4.46, 5.81). Inlet Run (site 15) in Conneaut Outlet sub-basin had the lowest HBI score (3.01) followed by the 2 sites in Sugar Creek sub-basin and Patchell Run (site 10) in French Creek sub-basin. The two sites on Le Boeuf Creek had the highest HBI values (8.6 and 7.6), followed by Woodcock Creek, Gravel Run (site 18) in French Creek and the mouth of Cussewago Creek.

The two sites in Le Boeuf sub-basin had particularly high percentages of Diptera (72% and 55%). Most of these Diptera are part of the family Chironomidae. The overall mean % Chironomidae was 18% (9, 26). The two sites in Le Boeuf sub-basin had particularly high percentages of Chironomidae (71% and 54%).

Discussion of Results

Several studies have shown that certain macroinvertebrate metrics either increase or decrease (become impaired) with perturbation (e.g. Barbour et al. 1994, Barbour et al. 1996, DeShon 1995, Fore et al. 1996, Smith and Voshell 1997). By knowing how certain macroinvertebrates respond to water quality, we can begin to make statements about habitat and water quality at particular sites.

Later in this report, we analyze the relationships between macroinvertebrate metrics and water quality, land-use and habitat parameters. Macroinvertebrate responses to impairment of these parameters will be compared to established indices. We will then be able to better describe trends we see in the macroinvertebrate data. For instance, if we show that number of EPT taxa decrease with increased sedimentation; we can relate levels of sedimentation at a particular site with number of EPT taxa.

Analysis and Results

Between sub-basins

We examined water quality parameters to determine if they varied between sub-basins. Mean values of water quality parameters for each sub-basin are reported in Table 5 and 6. To assess the significance of differences in water quality parameters between sub-basins, we used one-way ANOVAs (Analysis of Variance). Significance was assessed at the $\alpha = 0.05$ level. Results of the ANOVAs are reported in Table 7. We found significant differences between sub-basins for several water quality parameters.

Significant differences between sub-basins were further assessed by comparing each sub-basin to the entire watershed. We did this to determine if any of the sub-basins stood out as potential problem areas compared to what was typical of the watershed. To test if sub-basin means were different from the overall mean, we compared 95% confidence intervals. First, we calculated the overall mean and 95% confidence interval (denoted by two numbers in parenthesis following the mean) for each parameter using all the data for the entire watershed. If the sub-basin mean did not fall within the overall 95% confidence interval, there is significant difference at the $\alpha = 0.05$ level (Table 5 and 6). These analyses give us a good picture of which sub-basins are outliers compared to what was typically observed for the whole watershed.

Table 5: Mean values of water quality, habitat, and land-use parameters for each sub-basin. These values were compared to the mean and 95% confidence intervals for the entire French Creek watershed. Bolded values are significantly lower than the overall mean at the $\alpha=0.05$ significance level.

		Conneaut	**Conneauttee**	**Cussewago**	**French Creek**	**Le Boeuf**	**Little Sugar**	**Muddy**	**South Branch FC**	**Sugar**	**West Branch FC**	**Woodcock**
Percent Forest		**46.2**	49.5	49.9	56.3	**45.6**	51.3	56.4	54.8	71.0	57.0	49.9
Habitat/Riparian 1		77.5	83	78.5	79	**64**	**73**	98.5	83	99	**75**	87
Habitat/Riparian 2		74	79	**70**	83	**64**	83	88.5	80.5	103	**69**	98
Total Habitat/Riparian		159	**143**	**148.5**	156	**128**	**151**	187	160.5	193	**144**	188
DO (%)	Spring	**96.6**	99.9	98.2	100.3	**96.5**	99.3	**96.6**	100.1	99.8	**95.9**	99.2
	Base	**73.8**	**84.1**	**70.5**	113.2	**83.9**	96.8	110.8	98.2	112.5	96.6	113.6
	Summer	**64.9**	**80.7**	92.2	103.3	**77.9**	162.4	94.7	100.5	113.3	102.1	**90.9**
DO Concentration	Spring	**10.36**	11.23	10.83	11.07	**10.46**	10.75	**10.47**	10.98	11.04	10.59	10.83
	Base	**6.42**	**7.77**	**6.39**	9.91	**7.38**	9.03	9.61	8.65	10.54	8.66	9.95
	Summer	**6.04**	**7.46**	**8.29**	9.20	**7.29**	15.27	8.79	9.27	10.75	9.49	**8.02**
pH	Spring	**7.34**	7.39	7.38	**7.48**	7.41	7.40	7.38	**7.46**	**7.31**	7.38	7.38
	Base	**7.73**	**7.83**	**7.68**	8.25	**7.60**	8.04	**7.96**	**7.94**	8.21	**7.88**	8.12
	Summer	**7.47**	**7.77**	8.03	8.04	7.92	7.87	8.00	8.04	8.00	7.97	8.04

Table 6: Mean values of water quality and land-use parameters for each sub-basin. These values were compared to the mean and 95% confidence intervals for the entire French Creek watershed. Bolded values are significantly higher than the overall mean at the α=0.05 significance level.

		Conneaut	**Conneauttee**	**Cussewago**	**French Creek**	**Le Boeuf**	**Little Sugar**	**Muddy**	**South Branch FC**	**Sugar**	**West Branch FC**	**Woodcock**
Percent Agriculture		37.6	**45.1**	38.6	39.8	**44.7**	**44.7**	37.2	39.4	27.2	36.4	38.6
N, nitrate + nitrite (mg/L)	Spring	0.22	**0.68**	0.41	**0.58**	0.34	**0.79**	**0.62**	**0.61**	0.38	0.26	0.52
	Base	0.18	**1.63**	0.20	0.40	0.23	0.46	0.23	0.68	0.37	0.56	0.20
	Summer	0.17	**2.97**	0.36	0.34	0.69	0.53	0.05	**0.76**	**0.75**	**0.84**	0.12
P, total (mg/L)	Spring	0.15	0.08	0.10	0.14	0.12	**0.20**	0.11	0.10	0.14	**0.19**	**0.28**
	Base	0.08	**0.18**	0.11	0.04	0.08	0.08	0.07	0.09	0.08	0.09	0.03
	Summer	**0.23**	**0.22**	0.04	0.06	**0.10**	**0.10**	0.09	**0.11**	0.05	0.04	0.08
N, kjeldahl (mg/L)	Spring	0.9	0.8	1.2	1.0	1.2	1.2	1.2	1.1	1.3	1.0	0.8
	Base	**1.4**	1.0	1.1	0.9	0.9	0.8	1.0	0.9	0.7	**1.4**	0.8
	Summer	**1.8**	1.2	1.4	1.0	0.8	1.3	0.7	1.1	0.7	**3.0**	1.0
TDS (mg/L)	Spring	**120**	**130**	88	**120**	**130**	110	91	**130**	66	**140**	110
	Base	**240**	**270**	180	200	210	190	175	**230**	140	**235**	140
	Summer	180	**260**	**220**	190	**230**	210	170	**225**	180	**225**	120
SS (mg/L)	Spring	37	12	11	43	12	66	**92**	30	23	33	**74**
	Base	6	6	6	5	5	6	5	5	5	7	5
	Summer	**71**	16	10	10	18	**44**	**27**	19	5	6	**36**
N, ammonia (mg/L)	Spring	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Base	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Summer	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BOD (mg/L)	Spring	4	4	NA	4	4	4	4	4	4	4	4
	Base	4	4	4	4	4	4	4	**257**	4	4	4
	Summer	4	4	4	4	4	4	4	4	4	4	4
N, organic (mg/L)	Spring	0.65	0.00	0.80	0.50	0.70	0.40	**1.00**	0.60	**1.10**	0.75	0.30
	Base	**0.90**	-0.80	**1.10**	0.50	**0.70**	0.30	**0.70**	0.30	0.45	**0.75**	0.50
	Summer	**1.50**	-1.80	**1.00**	0.45	0.10	0.80	0.70	0.35	-0.10	**2.10**	0.90
Temperature (°C)	Spring	**12.09**	10.36	11.00	11.20	**11.54**	**11.82**	11.38	11.00	**11.69**	11.11	11.41
	Base	21.18	18.50	20.34	**23.07**	19.97	17.49	21.36	**21.55**	19.44	**22.07**	**21.90**
	Summer	18.76	19.12	**20.53**	**20.31**	18.51	18.31	18.94	19.25	17.85	18.84	**21.52**
Specific Cond. (mS/cm)	Spring	0.17	0.26	**0.14**	0.19	**0.21**	0.15	0.15	0.17	0.14	0.20	0.14
	Base	**0.36**	**0.41**	0.26	0.32	**0.34**	0.29	0.24	0.32	0.21	**0.38**	0.22
	Summer	0.24	**0.41**	0.24	0.29	**0.32**	0.25	0.24	0.29	0.22	**0.35**	0.18
Conductivity (mS/cm)	Spring	0.13	**0.18**	0.10	0.14	**0.15**	0.11	0.11	0.12	0.11	**0.15**	0.10
	Base	**0.33**	**0.37**	0.23	**0.30**	**0.33**	0.25	0.22	**0.30**	0.19	**0.34**	0.20
	Summer	0.21	**0.37**	0.22	0.26	**0.28**	0.22	0.21	0.26	0.19	**0.31**	0.16
Salinity (ppt)	Spring	0.08	**0.12**	0.07	0.09	**0.10**	0.07	0.07	0.08	0.07	**0.10**	0.07
	Base	**0.17**	**0.20**	0.12	0.15	**0.17**	0.14	0.11	0.15	0.10	**0.18**	0.11
	Summer	0.11	**0.20**	**0.11**	0.14	0.15	0.12	0.11	0.14	0.10	**0.17**	0.08

Table 7: Results of the ANOVAs comparing sub-basin means of water quality parameters for each sampling event. Significant (p-value <0.05) results are in bold type.

	Spring Rain		Base Flow		Summer Rain	
	F- value	p-value	F- value	p-value	F- value	p-value
N, nitrate + nitrite (mg/L)	**8.32**	**.000**	**3.36**	**.001**	**23.63**	**.000**
Phosphorus, total (mg/L)	1.01	.447	**2.70**	**.005**	**8.82**	**.000**
N, kjeldahl (mg/L)	1.23	.278	**2.62**	**.006**	**3.41**	**.013**
TDS (mg/L)	**5.35**	**.000**	**7.49**	**.000**	1.79	.140
SS (mg/L)	**2.13**	**.025**	1.33	.223	**4.29**	**.004**
N, ammonia (mg/L)	0.30	.984	**2.31**	**.015**	.658	.747
BOD (mg/L)	NA	NA	1.28	.323	.049	.999
N, organic (mg/L)	1.63	.104	**2.65**	**.006**	**5.38**	**.001**
Temperature (°C)	1.29	.268	**4.04**	**.000**	**4.16**	**.005**
Conductivity (mS/cm)	**3.62**	**.002**	**9.37**	**.000**	**3.72**	**.008**
Salinity (ppt)	**3.50**	**.002**	**8.50**	**.000**	**4.41**	**.004**
DO (%)	0.89	.549	**3.91**	**.000**	**3.71**	**.009**
DO (mg/L)	0.69	.752	**4.04**	**.000**	**4.19**	**.005**
pH	0.79	.634	**4.79**	**.000**	1.64	.177

Land-use

There is approximately 721,000 acres of land in the Pennsylvania portion of the French Creek watershed. Agriculture encompasses 38.0% of the land use while 55.8 % is forested land (Figures 2 and 4). The average percent agriculture for the entire watershed was 38.6% (35.7,41.6). Sub-basins with significantly higher than average percent agriculture were Le Boeuf (44.7%), Little Sugar (44.7%), and Conneauttee (45.1%). Sugar Creek had significantly lower than average percent agriculture (27.2%). The mean percentage of forested land for the entire watershed is 51.3% (47.1, 55.5). Only Sugar Creek was significantly higher than the watershed average, with 71% forested land. Those with significantly lower percent forested land were Le Boeuf (45.6%) and Conneaut (46.2%).

Habitat/Riparian Assessment

No significant differences were found between sub-basins for habitat/riparian score 1, which focuses on in-stream habitat (p-value = 0.07), habitat/riparian score 2 which focuses on riparian habitat (p-value = 0.15), or total habitat/riparian score (p-value = 0.08).

The overall mean for habitat/riparian score 1 was 79.6 (75.7,83.6). Habitat score 1 was significantly lower than the watershed mean in Le Boeuf and Little Sugar sub-basins. High areas of sediment deposition, for example, in Little Sugar Creek contributes to the low scores here. Habitat/riparian score 1 was significantly higher than the mean in Sugar Creek, Muddy Creek and Woodcock Creek sub-basins.

The overall mean for habitat/riparian score 2 was 79.6 (75.2,84.1). Habitat score 2 was significantly lower than the watershed mean in Conneaut, Cussewago, Le Boeuf and West Branch French Creek sub-basins. Thin riparian vegetative zones in Watson Creek and Rock Creek in the Conneaut sub-basin and Rundeltown Run and near the mouth of the Cussewago in the Cussewago sub-basin particularly contribute to low scores. Trout Run in Le Boeuf sub-basin had particularly low scores, showing problems with all aspects of the assessed habitat. Habitat/riparian score 2 was significantly higher than the mean in Sugar Creek, Muddy Creek and Woodcock Creek sub-basins.

The overall mean total habitat/riparian score was 159.3 (151.6,167.0). Total score was significantly lower than the overall mean for Le Boeuf, Conneauttee, West Branch French Creek, Cussewago, and Little Sugar Creek sub-basins. Muddy Creek, Sugar Creek and Woodcock Creek sub-basins had higher than average total habitat/riparian scores.

Salinity

The mean salinity for the spring rain event was 0.09 ppt (0.08,0.09), and the maximum salinity measured was 0.16ppt. The means for base flow and summer rain were both 0.14 ppt (0.13,0.15). The maximum salinity measurement was during the base flow (0.42 ppt) at Darrows Brook in Conneauttee sub-basin. Other points above 0.20ppt during the base flow were 2 sites in Conneaut sub-basin (Conneaut Outlet confluence with Mc Michaels Run and Watson Run), 2 sites in Conneauttee sub-basin (Darrows Brook and Conneauttee Creek confluence with Darrows Brook), and Trout Run in Le Boeuf sub-basin.

Temperature

Although some differences in temperature were observed during the spring rain event, biologically speaking, there is no reason for concern. However, when temperatures rise above optimal or tolerable levels for fish and/or mussels during the summer, there is reason for concern. The mean temperature for all sub-basins during the spring flow was 11.16 ˚C (10.9, 11.4). The mean temperature for the base flow was 20.9˚C (20.4, 21.5). The mean temperature during the summer rain event was 19.8˚C (19.4, 20.2). During base flow, French creek main-stem mean temperature (23.1˚C) was significantly higher than the watershed mean, as were mean temperatures for South Branch (21.6˚C), West Branch French Creek (22.1˚C) and Woodcock Creek (21.9˚C). Two sites were dry during the base flow sampling period, Navy Run in Muddy Creek sub-basin and an unnamed tributary to Hubbel Run in the main-stem sub-basin. Forty-six sites had above average base flow temperatures (Table 8, Figure 5).

According to the Pennsylvania Code Title 25 Chapter 93, French Creek is designated as a warm water fishery, and temperature limits during the base flow event (early September) should not exceed 28.9˚C. Although several sites had temperatures in the upper 20's, only one site had temperatures above 28.9˚C during the base flow-sampling, site 60 at the mouth of Mill Run. To maintain cold-water fisheries, as some of the tributaries to French Creek are designated, 17.8˚C is the maximum temperature level.

Figure 5: Habitat/riparian score 2 and base flow temperatures in the French Creek watershed

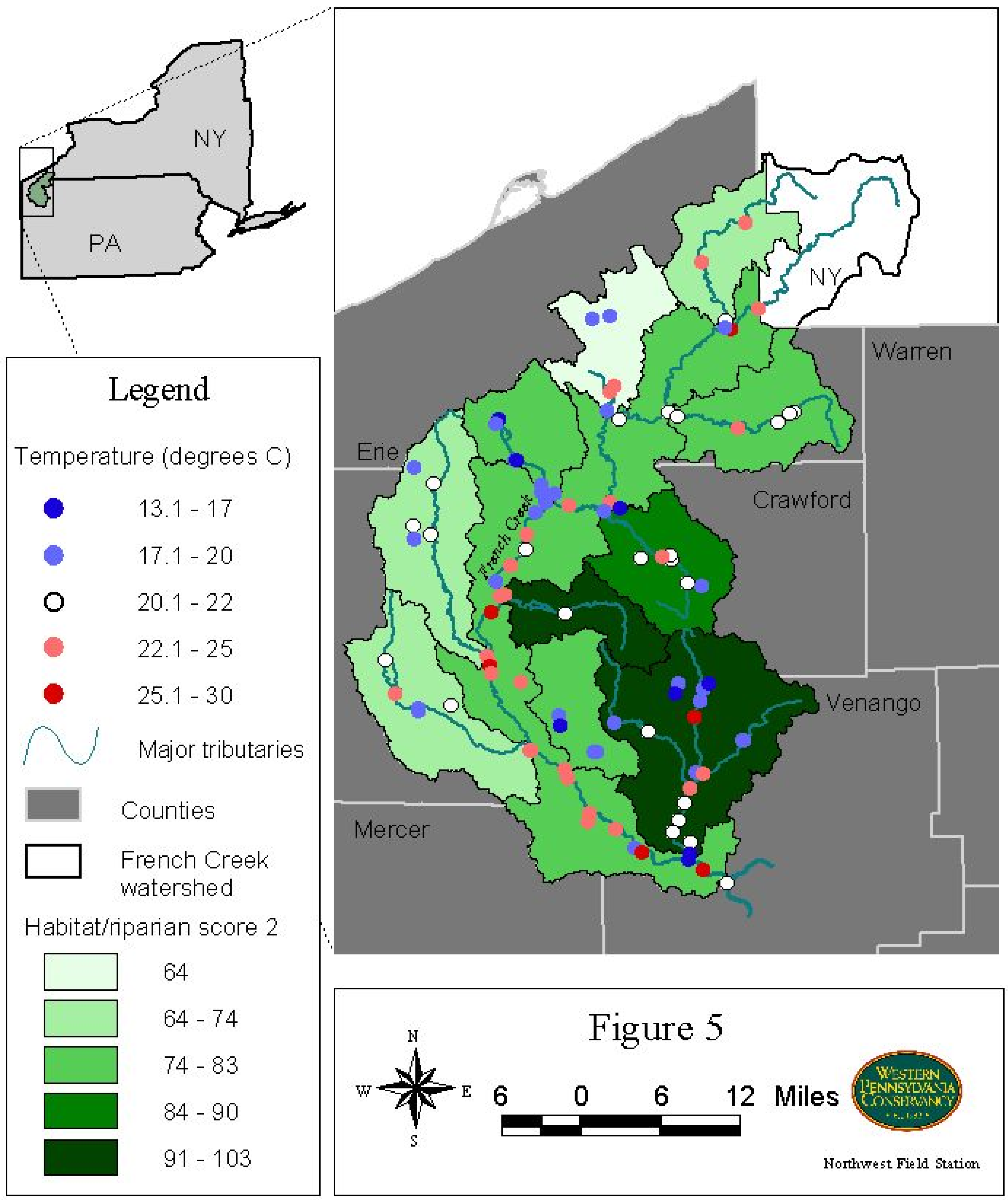


Table 8: Sites with significantly higher than average base flow temperatures (> 21.5 °C).

WQ site Number	Sub-basin	Site Name/Description	Temperature ° C
WQ60	French Creek	Mill Run (mouth)	29.15
WQ104	French Creek	FC us Franklin	26.81
WQ50	French Creek	FC us Cussewago Creek	26.17
WQ2	French Creek	Hubbel Run (mouth)	25.72
WQ87	Sugar Creek	West Branch Sugar Creek (mouth)	25.22
WQ80	French Creek	FC ds Utica	25.16
WQ45	French Creek	FC us Wolf Run	25.06
WQ62	French Creek	FC us Conneaut Outlet	24.97
WQ64	Conneaut	Conneaut Outlet ds Conneaut Lake	24.50
WQ78	French Creek	FC us Mill Creek and Utica	24.49
WQ75	French Creek	FC ds Cochranton	24.47
WQ76	French Creek	FC us North Deer Creek	24.44
WQ59	French Creek	Mill Run ds Tamarack Lake	24.32
WQ69	French Creek	FC us Little Sugar Creek	24.31
WQ95	Sugar Creek	Lake Creek (mouth)	23.86
WQ1	French Creek	FC on NY Border, us Hubbel Run	23.61
WQ58	French Creek	FC us Mill Run	23.42
WQ31	French Creek	FC us Cambridge Springs	23.24
WQ57	Cussewago Creek	Cussewago Creek (mouth)	23.20
WQ19	Le Boeuf	Le Boeuf Creek ds Lake Le Boeuf	23.17
WQ61	French Creek	FC ds Meadville	23.12
WQ12	South Branch FC	South Branch FC us Union City	23.07
WQ17	Le Boeuf	Le Boeuf Creek us Lake Le Boeuf	23.04
WQ47	French Creek	FC us Woodcock Creek	23.02
WQ43	French Creek	FC ds Venango	23.00
WQ49	Woodcock Creek	Woodcock Creek (mouth)	22.96
WQ91	Sugar Creek	East Branch Sugar Creek 2	22.85
WQ28	Muddy Creek	Muddy Creek us Mackey Run	22.82
WQ68	Conneaut	Conneaut Outlet (mouth)	22.82
WQ5	West Branch FC	West Branch FC us Alder Run	22.77
WQ101	Sugar Creek	Sugar Creek us Lick Run	22.75
WQ21	French Creek	FC us Muddy Creek	22.59
WQ42	French Creek	FC us Venango	22.49
WQ77	French Creek	North Deer Creek (mouth)	22.29
WQ4	West Branch FC	West Branch FC near NY Border	22.22
WQ74	Little Sugar Creek	Little Sugar Creek (mouth)	22.12
WQ26	Muddy Creek	Muddy Creek us Federal Run	21.96
WQ6	West Branch FC	West Branch FC us Wattsburg	21.92
WQ56	Cussewago Creek	Carr Run (mouth)	21.92
WQ29	Muddy Creek	Mackey Run	21.79
WQ44	French Creek	Gravel Run (mouth)	21.74
WQ63	Conneaut	Inlet Run us Conneaut Lake	21.72
WQ99	Sugar Creek	Sugar Creek us Warden Run	21.64
WQ32	French Creek	FC us Conneauttee Creek	21.63
WQ9	South Branch FC	South Branch FC us Slaughter Run	21.57
WQ10	South Branch FC	Slaughter Run	21.55

Dissolved Oxygen

In nearly all unpolluted streams and rivers, DO concentrations stay above 80% saturation (Hauer and Hill 1996). Although some sites in the spring rain event fell short of the watershed mean DO concentration of 98.0 % (96.8, 99.3), no sites had DO concentrations below 80% saturation. However, during the summer base flow event, 22 sites fell below that level. There were significant differences in base flow DO between sub-basins (p-value =0.00). The mean DO concentration for the base flow event was 98.0 % (92.1,103.9). The mean DO concentration in Cussewago sub-basin was only 70.0% (32.7,95.7), with 6 sites below 72%. A low DO of 12.4% was measured in West Branch Cussewago Creek (site 52), and 27.1 at Cussewago Creek (site 51). Mean DO in Conneaut sub-basin was 73.8% (34.3,92.8) with lows of 20.9% at the confluence of Conneaut Outlet and Mc Michael Run (site 65) and 38.8% at Mc Michael Run (site 66). Although the overall mean for Le Boeuf Creek was over 80%, levels were still significantly less than the overall FC watershed mean. Sites such as the confluence of Le Boeuf Creek and East Branch Le Boeuf Creek (site 15, 35.0%) and the mouth of Le Boeuf Creek (site 20, 69.7%) brought down the overall mean. Similarly, Conneauttee Creek had a mean of 84.1%, but had a few sites with very low DO saturation; Darrows Creek (site 36, 20.0%) and Shenango Creek (site34, 65.4%). Although the mean DO level in the main stem of French Creek was not significantly different from the whole watershed, there were a few sites that had quite low DO levels, particularly Torry Run (site 38, 25.1%), Wolf Run (site 46, 69.9%), and Mill Run (site 59, 75.5%). Sites 93 and 94 on Lake Creek in the Sugar Creek sub-basin should also be noted, with dissolved oxygen saturation at 20.5 and 21.9%, respectively. Table 9 lists sites with significantly lower base flow dissolved oxygen (below 80% saturation and/or below 7.0 mg/L). Figure 6 illustrates base flow dissolved oxygen levels.

According to the Pennsylvania Code Title 25 Chapter 93 warm water fishery designation, minimum daily average of dissolved oxygen concentrations should be at least 5.0 mg/L. Although several sites had dissolved oxygen below 5.0 mg/L at the time of sampling, we were unable to measure DO throughout the day to calculate the average daily rate.

The mean DO saturation during the summer rain event was 98.7% (91.6,105.9). Only 4 sites fell below 80% saturation; two sites on the main stem of French Creek; site 31 at Cambridge Springs (66.4%) and site 32 at Conneauttee Creek (66.4%), one site at the mouth of Conneaut Outlet (site 68, 64.9%) in Conneaut sub-basin, and the mouth of Le Boeuf Creek (site 20,77.9%). The mean DO saturation during the spring rain event was 98.0% (96.8,99.3), and no sites fell below 86% saturation.

Biological oxygen demand (BOD)

Only two readings for BOD were above the mean for all sites; site 13, the mouth of South Branch French Creek (513mg/L) and site 61, French Creek below Meadville (13mg/L). Both readings were taken during the base flow event.

Figure 6: Percent forested land and base flow dissolved oxygen percentages in the French Creek watershed

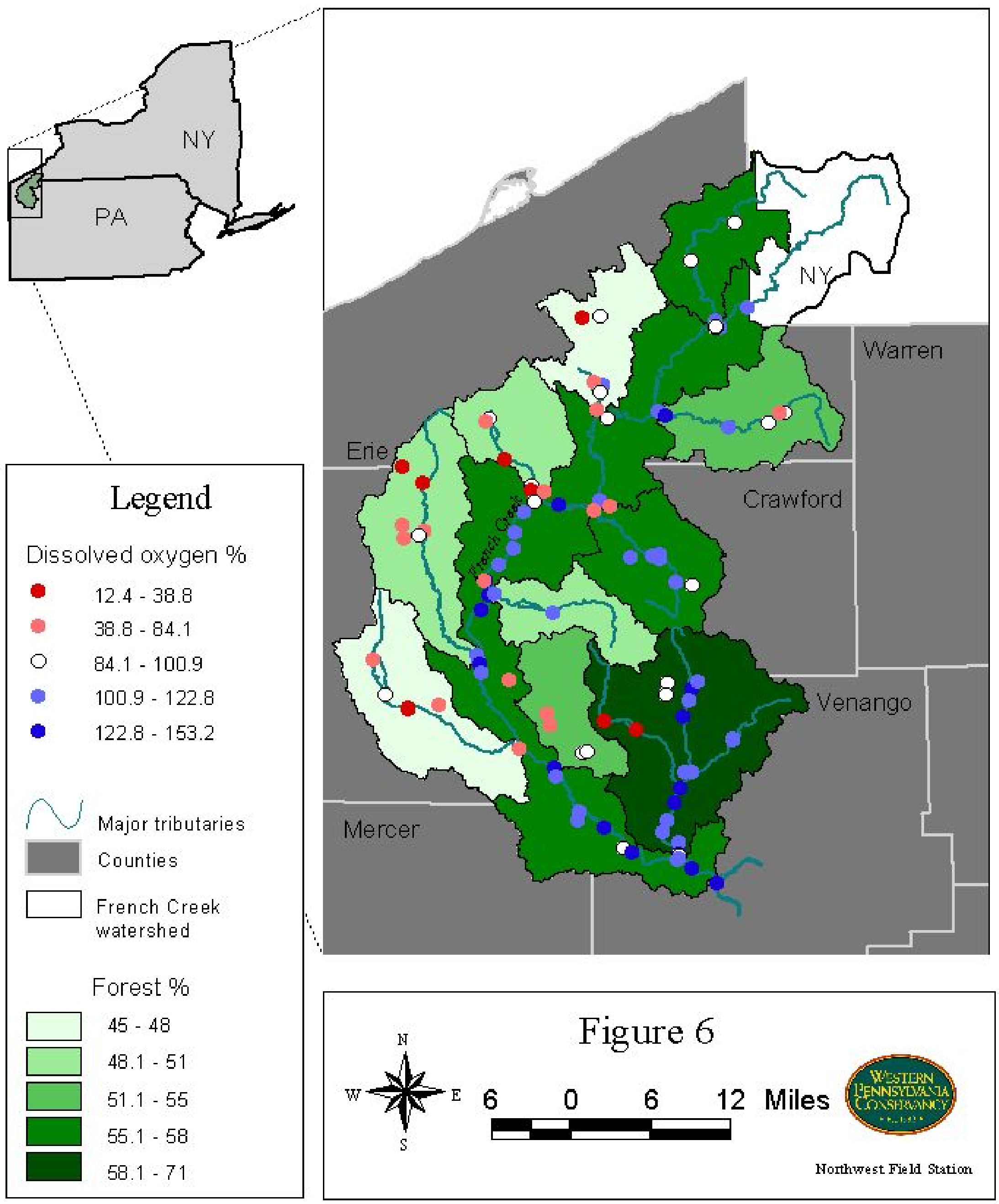


Table 9: Sites with significantly lower base flow dissolved oxygen (below 80% saturation and/or below 7.0 mg/L).

WQ Site Number	Sub-basin	Site Name/Description	DO %	DO (mg/L)
52	Cussewago Creek	West Branch Cussewago Creek	12.4	1.15
36	Conneauttee Creek	Darrows Creek (mouth)	20.0	2.08
94	Sugar Creek	Lake Creek ds Sugar Lake	20.5	1.85
65	Conneaut	Conneaut Outlet us Mc Michael Run	20.9	1.94
93	Sugar Creek	Lake Creek us Sugar Lake	21.9	2.01
38	French Creek	Torry Run	25.1	2.34
51	Cussewago Creek	Cussewago Creek us West Branch CC	27.1	2.44
15	Le Boeuf	Le Boeuf Creek us East Branch Le Boeuf	35.0	3.18
66	Conneaut	McMichael Run	38.8	3.66
34	Conneauttee Creek	Shenango Creek	65.4	6.12
63	Conneaut	Inlet Run us Conneaut Lake	69.5	6.11
20	Le Boeuf	Le Boeuf Creek (mouth)	69.7	6.65
46	French Creek	Wolf Run (mouth)	69.9	6.49
55	Cussewago Creek	Rundelltown Creek	70.2	6.39
54	Cussewago Creek	Carr Run us Rundelltown Creek	70.5	6.28
53	Cussewago Creek	Cussewago Creek us Carr Run	71.3	6.47
71	Little Sugar Creek	Mud Run	74.3	7.36
59	French Creek	Mill Run ds Tamarack Lake	75.5	6.32
70	Little Sugar Creek	Little Sugar Creek us Mud Run	76.5	7.31
22	Muddy Creek	Kelly Run (mouth)	76.8	7.42
68	Conneaut	Conneaut Outlet (mouth)	78.1	6.72
67	Conneaut	Watson Run	79.4	7.12

pH

The mean pH was 7.4 (7.35,7.44) for the spring rain event, 8.1 (8.0,8.2) for base flow, and 8.0 (7.9,8.0) for the summer rain event. It doesn't appear that pH is a problem for most sites in the French Creek watershed. The minimum for all sites during the spring was 6.87, the base flow was 7.19, and the summer rain was 7.47. The maximums were 7.73, 9.38, and 8.21 for the spring, base, and summer events respectively.

Rain Sampling

Nutrient concentrations from the three sites where rain was collected during the spring rain event are illustrated in Figure 7. During the spring rain, the concentrations of organic nitrogen and kjeldahl nitrogen were high at the northernmost site (Lake Pleasant) and the mid-watershed site at Meadville. Levels of kjeldahl nitrogen were high at the southernmost site (Franklin). Concentrations of organic nitrogen and nitrogen (nitrate + nitrite) were about half that of kjeldahl nitrogen at Franklin.

Main-stem habitat evaluation

Figure 8 is a map of the large (>100 m length) flow regimes along the main-stem of French Creek. These flow regimes were used to evaluate potential study sites for future fish and mussel study.

Results from the riparian assessment on the main-stem sites show that the upper section (defined as French Creek above Cambridge Springs) had a mean riparian score of 58.5% (54.4, 62.6), the middle section (defined as French Creek between Cambridge Springs and Meadville) had a mean riparian score of 59.4% (54.0,64.8), and the lower section (defined as French Creek below Meadville) had a mean riparian score of 57.1% (54.2,60.0). The one-way ANOVA showed no significant difference between the 3 stream sections (F-value =0.92, p-value=0.40). The overall mean for all sites on French Creek was 58.1% (56.0, 60.3).

Discussion of Results

Temperature and dissolved oxygen are highly variable both spatially and temporally. Temperature is very important to aquatic organisms since many life history variables such as reproduction and growth are often regulated by temperature. Many stream organisms use temperature as a cue for emergence or spawning. Both temperature and dissolved oxygen fluctuate diurnally and between microhabitats. While mobile organisms can seek cool refuges, less mobile organisms such as freshwater mussels, cannot easily escape intolerable temperatures or levels of dissolved oxygen. For these reasons summer temperatures and dissolved oxygen should be studied in more detail.

Our study only provides a snapshot of these temporally varying parameters such as dissolved oxygen and temperature. Low DO levels observed at several sites warrant additional investigation, perhaps with permanent water quality monitoring stations.

Organic pollution, for instance, that linked with municipal sewage treatment discharge or industrial wastes, may drastically reduce DO concentrations as microbes consume oxygen. BOD is a measure of the microbial oxygen consumption, so attention should be made to the two sites with high BOD readings.

Use of salt to clear roads of ice can be a significant source of elevated concentrations of NaCl in stream water. Although we expected high salinity during spring runoff, this was not observed in our data. This is likely due to most road salts being washed downstream during snow melt prior to our spring sampling.

Recent studies have shown that the pH of acid rain in the French Creek watershed ranges between 4.33 and 4.39 (reported in French Creek Watershed Conservation Plan, WPC 2002). Although we did not observe acidic conditions in the streams, precipitation can also carry various chemical pollutants, including nitrogen and phosphorus. Rain samples showed a large amount of kjeldahl nitrogen and organic nitrogen added to the system from atmospheric sources, especially in the middle and northernmost portions of the watershed.

Sub-basins with high percentages of agriculture generally had high nutrient and sedimentation concentrations, and low habitat and/or riparian scores. These relationships will be discussed later in this report.

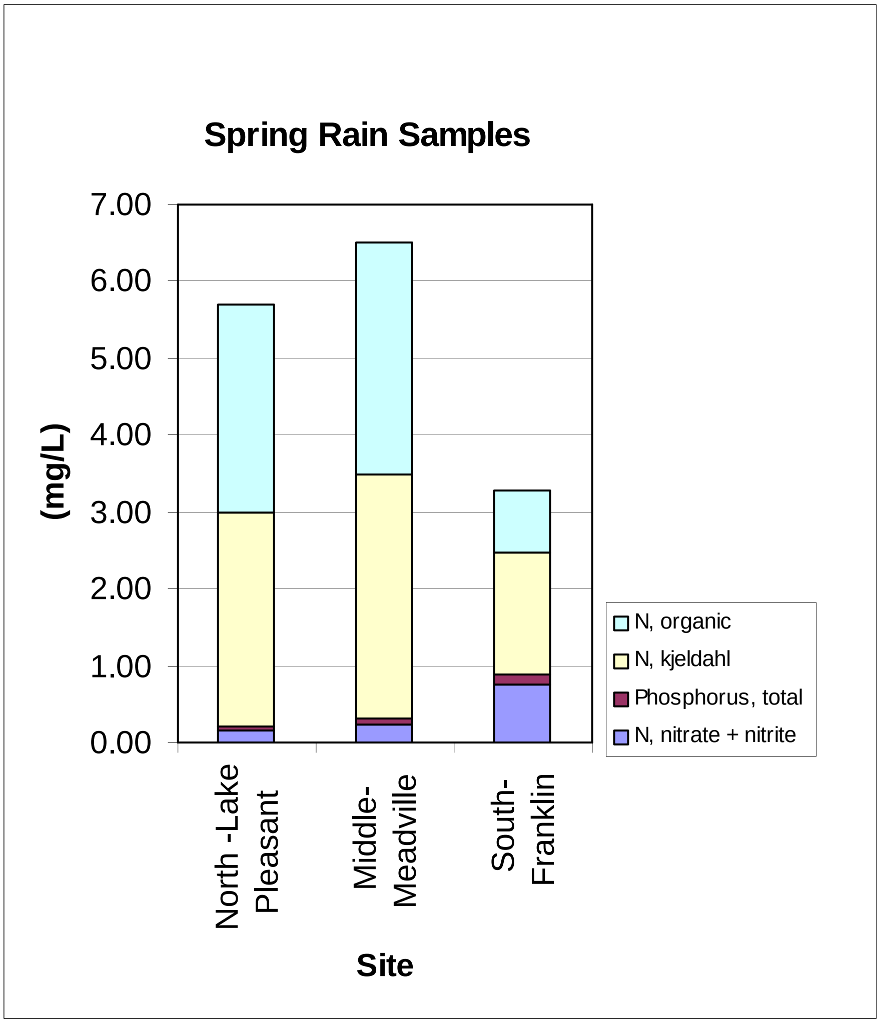
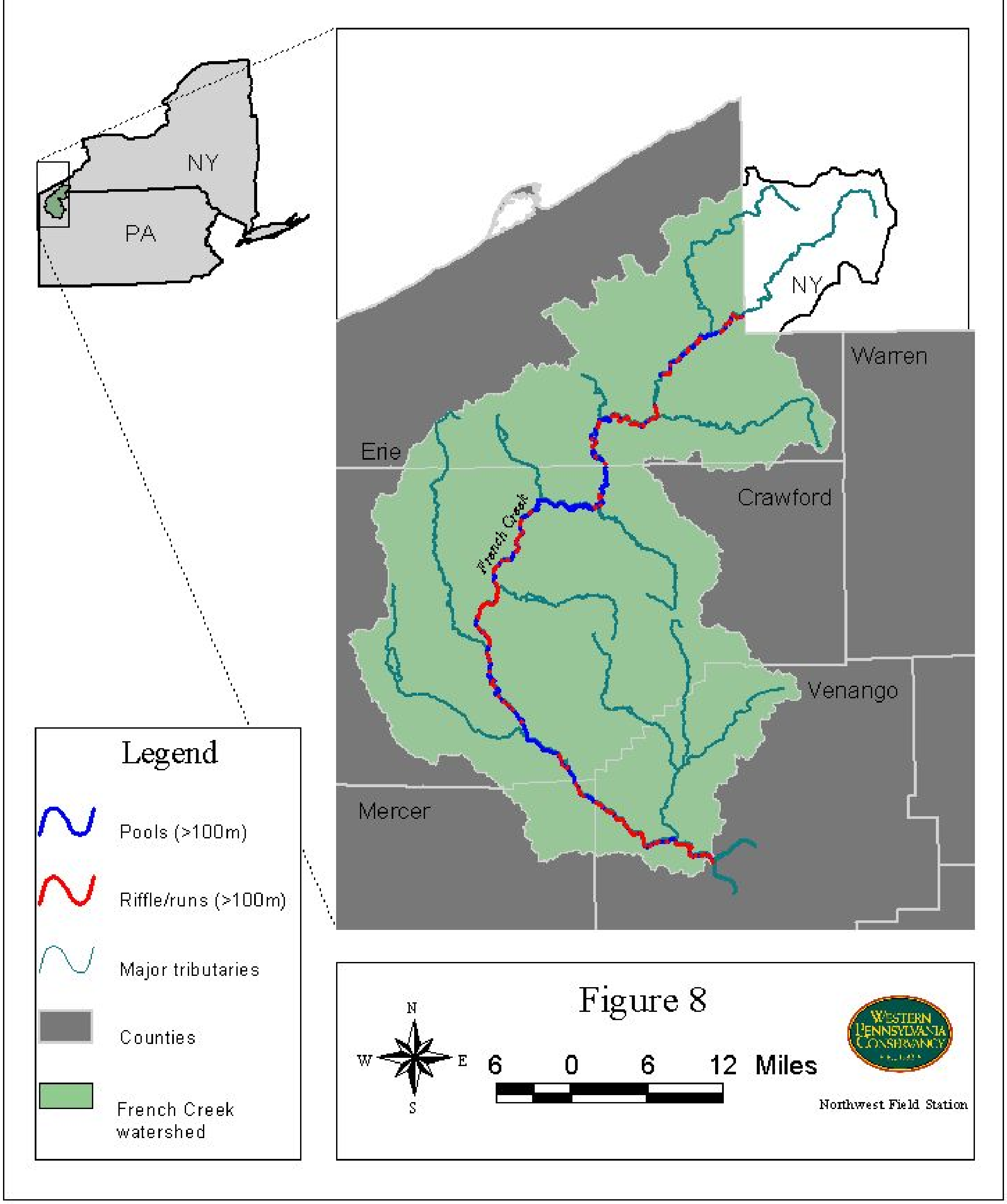


Figure 7: Nutrient concentrations from the three sites where rain was collected during the spring rain event.

Figure 8: In-stream habitat in the main-stem of French Creek



NUTRIENT LOADING RATES

Analysis and Results

Nutrient loading rates for 17 sites in the French Creek watershed are given in Table 10. Loading rates were calculated by multiplying the discharge and the nutrient concentrations at each site. To determine which sites are significantly different from what is typically observed in the entire watershed, we compared site-specific data to the mean and 95 % confidence intervals (denoted by two numbers in parenthesis following the mean) for all sites. Nutrient loading rates for main-stem sites are given in Table 11.

We expected a linear relationship between discharge and nutrient loading, as discharge increases so will the nutrient loading rates. We used simple least squares regression models to determine the rate at which the loading rates increase with increasing discharge. From this we are able to make predictions of nutrient loading rates at a given discharge. We calculated 95% simultaneous confidence intervals for the fitted regression lines to determine which of our data fall outside what is predicted by the model (Mathsoft 1999). We calculated separate models for main-stem loading rates, because discharge was substantially higher in the main-stem than in the sub-basins. Because very few data points were taken during the spring and summer rain events, we only calculated regression models for base flow.

Safety considerations and extremely high flows prevented water velocity measurements from being taken at all sites during the spring and summer rain events. Additionally, some sites were too deep or slow moving for accurate velocity measurements to be made even during the summer base flow sampling. Whenever possible, sampling sites were coordinated with active USGS gauging stations and discharge data was obtained from the USGS website. It should be noted that because water velocities were not taken at every site during every sampling period, discharge and nutrient loading rates were not calculated for those sites. Nutrient loading rates were not calculated on any sites in Conneaut Outlet or Conneauttee Creek during the summer rain event, in Sugar Creek or West Branch of French Creek during spring rain or summer base flow events, and in Woodcock Creek during the base flow event. The lack of measurements within these sub-basins must be taken into consideration when interpreting the following figures and tables.

Nitrogen (Nitrate + Nitrite)

Sub-basins

Nitrogen loading rates are illustrated in Figure 9. The highest nitrogen loading rates occurred during the spring rain event with a mean of 1.81 (0.66, 2.96). Site 67 on Watson Run in Conneaut Outlet had nitrogen loading rates above the 95% confidence interval (4.67 g/s) for the spring rain event. During the summer rain event, the mean nitrogen-loading rate was 0.75 g/s (0,1.53). During base flow, the mean nitrogen-loading rates were 0.09 g/s (0.02, 0.15). The mouth of South Branch French Creek (site 13) and the mouth of Sugar Creek (site 103) both had above average nitrogen loading rates during the summer rain and base flow sampling events.

We found a significant linear relationship, as discharge increases, nitrogen loading-rates increase (p-value=0.00). Four sites fell outside of the 95% simultaneous confidence intervals for nitrogen loading rates; Woodcock Creek (site 49) had lower than expected N loading rates and the mouth of West Branch French Creek (site 7), Watson Run (site 67) and Muddy Creek (site 23) had higher than expected N loading rates.

Main-stem French Creek

Instead of a linear relationship, we observed a log-linear increase in nitrogen loading, as discharge increased along the main-stem of French Creek, meaning the rate of increase seems to level off after a certain discharge. This trend is largely affected by the low nitrogen-loading rate observed at the mouth of French Creek at Franklin (0.25 g/s). One site that had a higher than expected nitrogen-loading rate, 0.93 g/s, site 61 below Meadville.

Total Phosphorus

Sub-basins

Phosphorus loading rates are illustrated in Figure 10. The highest phosphorus loading rates occurred during the spring rain event, with a mean of 0.54 (0, 1.22). Site 67 on Watson Run in Conneaut Outlet had phosphorus loading rates above the 95% confidence interval (2.50 g/s). During the summer rain event, the mean phosphorus-loading rate was 0.1 g/s (0,0.2). During base flow, the mean phosphorus-loading rates were 0.01 g/s (0, 0.02). Site 13, the mouth of South Branch French Creek and site 103, the mouth of Sugar Creek both had above average phosphorus loading rates during base flow. Watson Run on Conneaut Outlet (site 67), site 13, and site 103 all had above average phosphorus loading rates during the summer rain event.

We found a significant linear relationship, as discharge increases, phosphorus loading-rates increase (p-value=0.00). Three sites fell outside the 95% simultaneous confidence intervals for phosphorus loading rates; site 67, located at Watson Run on Conneaut Outlet had higher than expected phosphorus loading rates, and Woodcock Creek (site 49) and Sugar Creek (site 103) both had lower than expected phosphorus loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, phosphorus loading rates increase (p-value= 0.000). One site fell outside of the 95% simultaneous confidence intervals for phosphorus loading rates, site 61 below Meadville had higher loading rates than expected.

Kjeldahl nitrogen

Sub-basins

Kjeldahl nitrogen loading rates are illustrated in Figure 11. The highest kjeldahl nitrogen loading rates occurred during the spring rain event, with a mean of 5.36 g/s (1.91, 8.81). Site 16 on the East Branch of Le Boeuf Creek and site 67 on Watson Run in Conneaut Outlet had kjeldahl nitrogen loading rates above the 95% confidence interval (11.01 and 10.24 g/s). During the summer rain event, the mean kjeldahl nitrogen loading rate was1.25 g/s (0.37,2.14). During base flow, the mean kjeldahl nitrogen-loading rate was 0.17 g/s (0.05, 0.3). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) all had above average kjeldahl nitrogen loading rates during base flow. Site 13 and site 103 had above average kjeldahl nitrogen loading rates during the summer rain event.

Table 10: Discharge and loading rates for 17 sites in the French Creek watershed.

WQ site	Sub-shed		Discharge (cfs)			N (g/s)			P, total (g/s)			N, kjeldahl (g/s)			TDS (g/s)			SS (g/s)			N, ammonia (g/s)			N, organic (g/s)		
			Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer
7	West Branch FC	Mouth	*	5.6	21.2		0.17	0.54		0.01	0.03		0.24	2.28		42.8	138.1		1.0	4.2		0.02	0.06		0.07	1.74
10	South Branch FC	Slaughter Run	40.7	0.2	*	0.91	0.00		0.06	0.00		1.38	0.01		85.3	1.2		13.8	0.0		0.12	0.00		0.47	0.00	
13	South Branch FC	Mouth	*	13.5	70.9		0.26	1.65		0.05	0.30		0.50	2.01		114.7	421.6		1.9	42.2		0.04	0.20		0.24	0.36
16	Le Boeuf Creek	East Branch Le Boeuf	144.0	2.1	*	1.06	0.01		0.49	0.01		11.01	0.10		407.8	11.9		130.5	0.3		0.41	0.01		9.95	0.09	
18	Le Boeuf Creek	Trout Run	51.3	1.1	*	0.99	0.02		0.23	0.00		1.74	0.03		188.9	9.0		14.5	0.2		0.14	0.00		0.76	0.01	
20	Le Boeuf Creek	Mouth	*	2.2	7.0		0.07	0.14		0.00	0.02		0.06	0.16		13.3	45.6		0.3	3.6		0.01	0.02		-0.01	0.02
23	Muddy Creek	Muddy Creek	85.3	3.2	*	2.49	0.14		0.22	0.01		5.07	0.09		219.8	18.1		724.6	0.5		0.24	0.01		2.59	-0.05	
27	Muddy Creek	Federal Run (mouth)	175.0	2.0	*	2.43	0.01		0.30	0.01		4.46	0.06		436.1	9.6		89.2	0.3		0.50	0.01		2.03	0.06	
30	Muddy Creek	Mouth	*	3.1	22.1		0.00	0.03		0.01	0.06		0.07	0.44		14.7	106.4		0.8	16.9		0.01	0.06		0.07	0.44
33	Conneauttee Creek	Conneauttee	20.9	1.3	*	0.35	0.04		0.03	0.00		0.47	0.06		76.9	9.9		5.9	0.2		0.06	0.00		0.12	0.02	
48	Woodcock Creek	Woodcock Creek	351.0	4.1	28.0		0.03			0.00			0.10			18.6			0.6			0.01			0.07	
49	Woodcock Creek	Mouth	*	9.7	*		0.03			0.01			0.17			33.1			1.4			0.03			0.10	
51	Cussewago Creek	Cussewago	187.0	0.5	*	1.59	0.00		0.48	0.00		8.47	0.02		529.5	2.6		58.3	0.1		0.53	0.00		6.88	0.02	
57	Cussewago Creek	Mouth	*	1.3	4.1		0.01	0.04		0.00	0.01		0.03	0.16		4.4	25.5		0.2	1.2		0.00	0.01		0.02	0.12
67	Conneaut Outlet	Watson Run	402.0	8.4	*	4.67	0.12		2.50	0.04		10.24	0.31		1252	95.1		762.7	3.3		1.14	0.03		5.58	0.16	
74	Little Sugar Creek	Mouth	*	4.5	46.2		0.05	0.69		0.01	0.13		0.10	1.70		21.5	274.7		0.6	57.6		0.01	0.13		0.05	1.01
103	Sugar Creek	Mouth	*	24.7	102.2		0.48	2.17		0.04	0.14		0.98	2.03		111.8	520.9		3.5	14.5		0.07	0.29		0.50	-0.14

**Discharge was not calculated during this sampling period.*

Table 11: Discharge and nutrient loading rates calculated for sites on the main-stem of French Creek, including the mean loading rates for each sampling period are given.

WQ site	Sub-shed		Discharge (cfs)			N (g/s)			P, total (g/s)			N, kjeldahl (g/s)			TDS (g/s)			SS (g/s)			N, ammonia (g/s)			N, organic (g/s)		
			Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer
1	French Creek Main	Hubbel Run NY	816	7.0	20	11.32	0.02	0.18	1.85	0.02	0.04	37.0	0.30	0.85	3004	38	96	578	1	7	4.39	0.02	0.06	21.3	0.28	0.67
3	French Creek Main	West Branch	*	7.3	*	*	0.09			0.01			0.46			52			1			0.02			0.37	
8	French Creek Main	South Branch	*	11.5	*	*	0.05			0.01			0.26			65			5			0.03			0.21	
14	French Creek Main	Le Boeuf	*	26.4	*	*	0.46			0.03			0.75			134			4			0.07			0.29	
21	French Creek Main	Muddy	*	32.2	*	*	0.52			0.03			0.64			164			5			0.09			0.12	
47	French Creek Main	Woodcock	*	64.9	*	*	0.72			0.06			1.29			349			9			0.18			0.57	
61	French Creek Main	Meadville	4490	76.0	182	61.03	0.93	2.47	17.80	0.09	0.52	178.0	2.15	4.64	13986	430	876	6611	11	186	12.71	0.22	0.52	117.0	1.23	2.17
78	French Creek Main	Utica	6020	98.0	170	98.87	0.75		17.05	0.08		119.3	1.94		20456	666		4944	14		17.05	0.28		20.5	1.19	
105	French Creek Main	Mouth	*	112.1	*	*	0.25			0.10			2.86			603			16			0.32			2.60	
	MEAN					57.07	0.42	1.33	12.23	0.05	0.28	111.4	1.18	2.74	12482	278	486	4044	7	96	11.4	0.14	0.29	52.9	0.76	1.40

**Discharge was not calculated during this sampling period.*

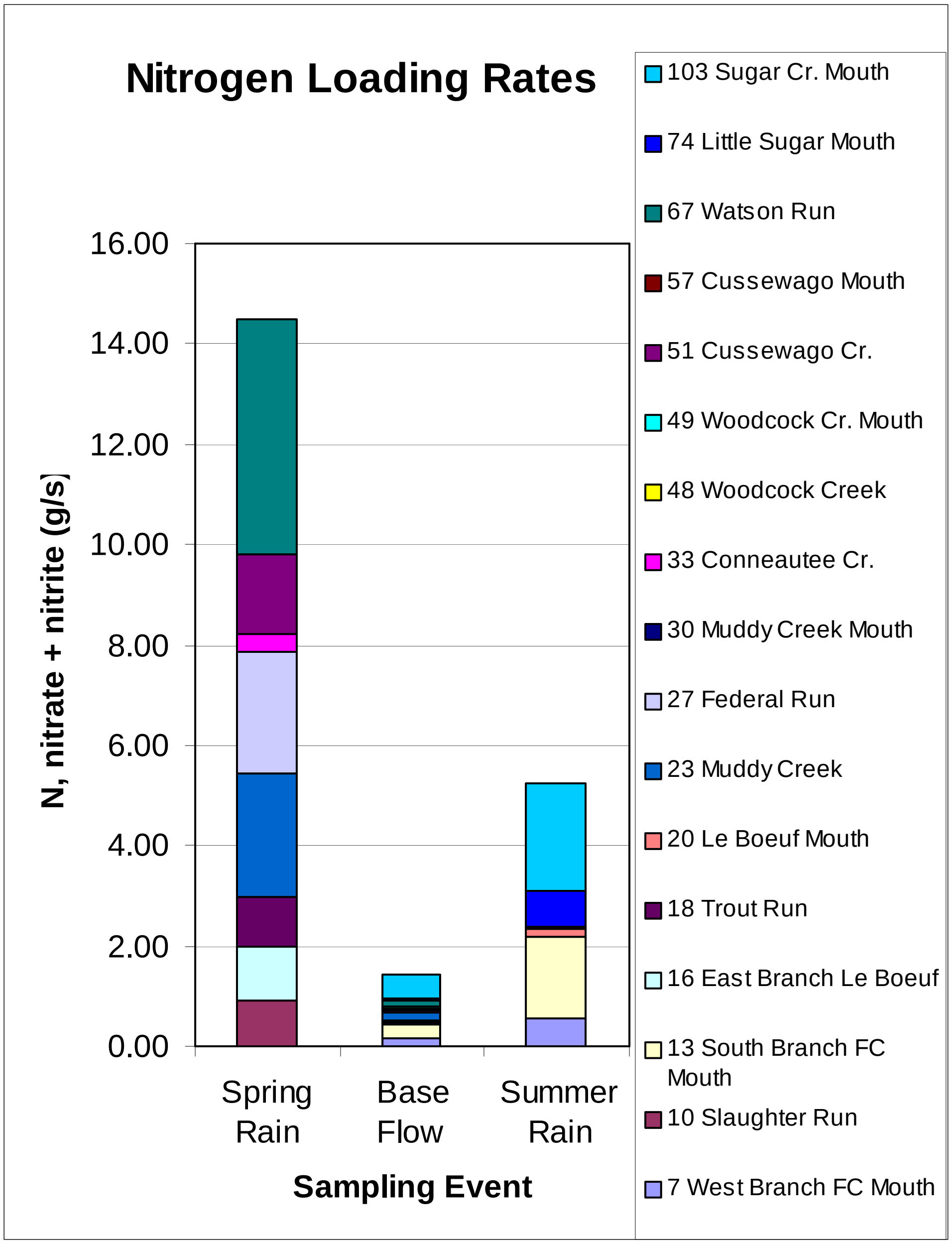


Figure 9: Nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

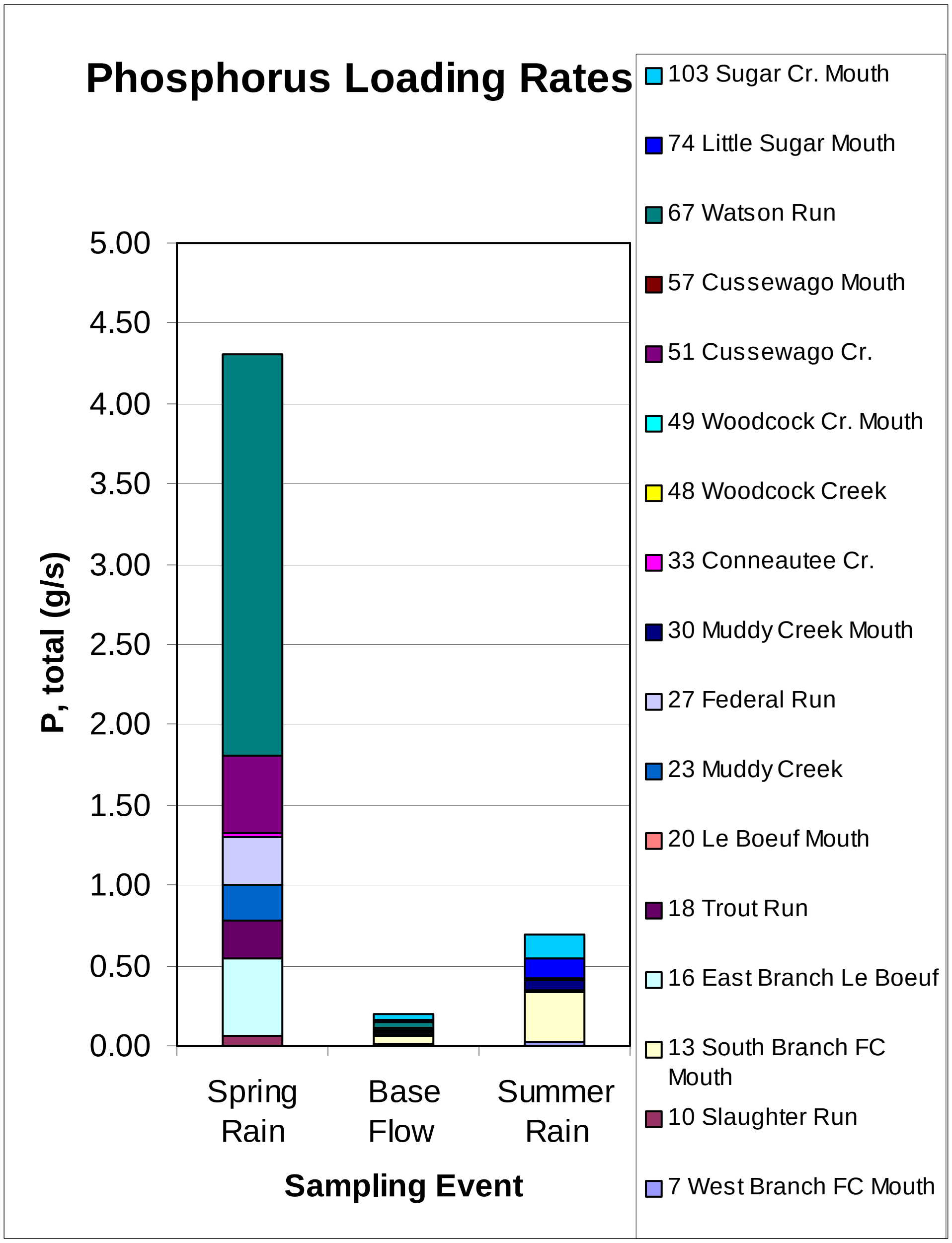


Figure 10: Phosphorus loading rates for 17 sites throughout the 10 sub-basins of French Creek watershed for three sampling events. (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

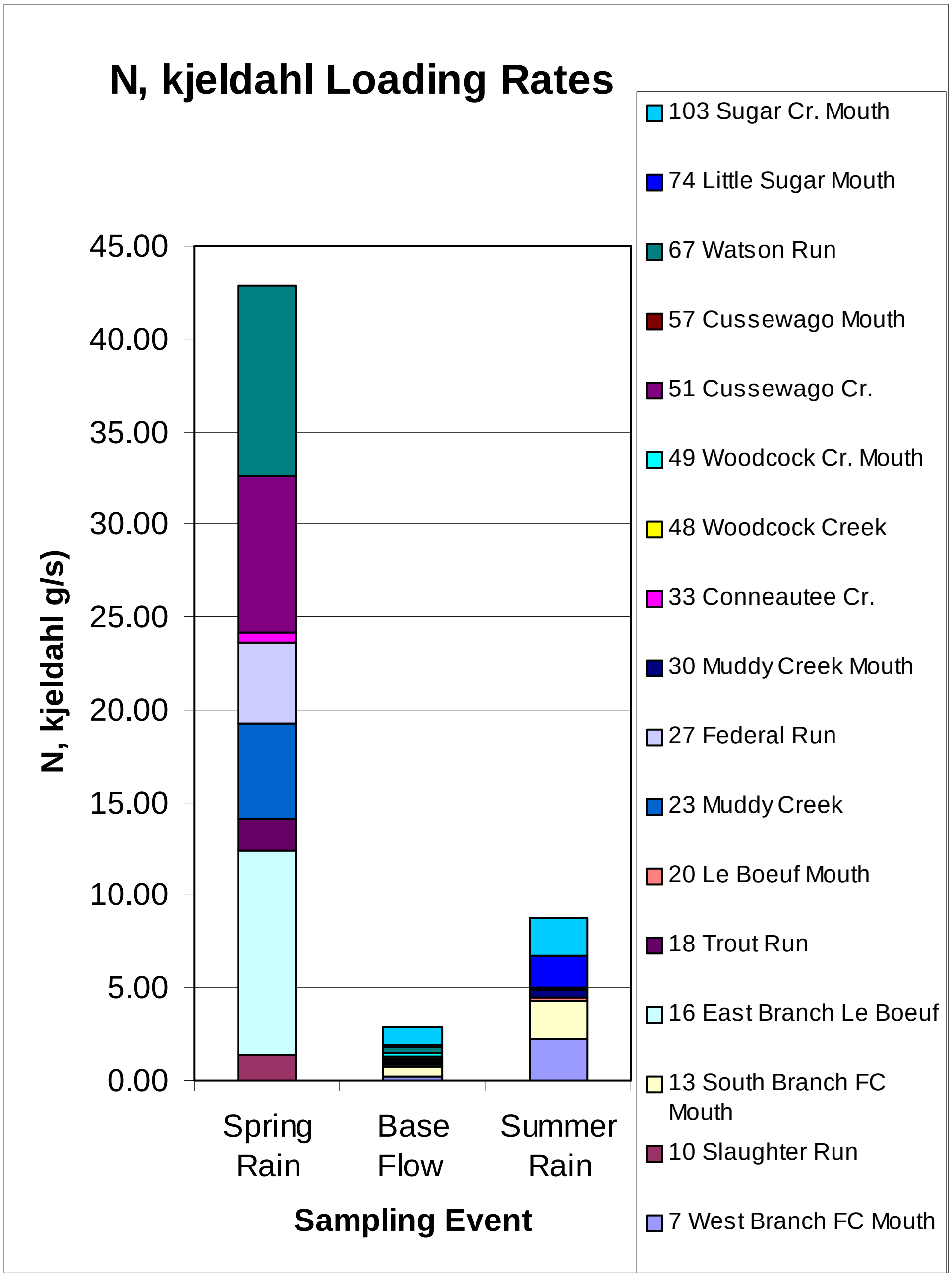


Figure 11: Kjeldahl nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

We found a significant linear relationship, as discharge increases, kjeldahl loading-rates increase (p-value =0.00). One site fell outside our 95% simultaneous confidence intervals for kjeldahl nitrogen loading rates; site 49 on Woodcock Creek had lower than expected kjeldahl nitrogen loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, kjeldahl loading-rates increase (p-value =0.00). Two sites fell outside of the 95% simultaneous confidence intervals for kjeldahl nitrogen loading rates, site 78 at Utica and site 47 at Woodcock Creek were both lower than expected.

Ammonia Nitrogen

Sub-basins

Ammonia loading rates are illustrated in Figure 12. The highest ammonia loading rates occurred during the spring rain event, with a mean of 0.39 g/s (0.1, 0.68). Site 67 on Watson Run in Conneaut Outlet had ammonia loading rates above the 95% confidence interval (1.14 g/s). During the summer rain event, the mean ammonia-loading rate was 0.11 g/s (0.02,0.21). During base flow, the mean ammonia-loading rate was 0.02 g/s (0.01, 0.02). The mouth of South Branch French Creek (site 13), the mouth of Woodcock Creek (site 49), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) all had above average ammonia loading rates during base flow. Only the mouth of Sugar Creek had an above average ammonia-loading rate during the summer rain-sampling event (0.29 g/s).

We found a significant linear relationship, as discharge increases, base flow ammonia loading rates increase (p-value =0.00). Two sites fell outside our 95% simultaneous confidence intervals for ammonia nitrogen loading rates; site 49 on Woodcock Creek, and Watson Run (site 67) both had loading rates lower than expected.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow ammonia loading rates increase (p-value =0.00). None of the sites fell outside of the 95% simultaneous confidence intervals for ammonia loading rates.

Suspended solids (SS)

Sub-basins

Suspended solids loading rates are illustrated in Figure 13. The highest suspended solids loading rates occurred during the spring rain event, with a mean of 224.94 g/s (0, 495.07). Site 23 on Muddy Creek and site 67 on Watson Run in Conneaut Outlet had suspended solids loading rates above the 95% confidence interval (724.63 and 762.69 g/s). During the summer rain event, the mean suspended solids loading rate was 20.0 g/s (0,40.0). During base flow, the mean suspended solids loading rate was 0.89 g/s (0.34, 1.44). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average suspended solids loading rates during base flow. Site 74 on Little Sugar Creek had an above average suspended solid loading rate during the summer rain-sampling event.

We found a significant linear relationship, as discharge increases, base flow suspended solids loading rates increase (p-value =0.00). Three sites fell outside of the 95% simultaneous confidence intervals for suspended solids loading rates. Site 67, located at Watson Run on Conneaut Outlet had a higher than expected loading rate. The mouth of Sugar Creek (site 103) and the mouth of South Branch French Creek (site 13), both had lower than expected suspended solid loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow suspended solids loading rates increase (p-value =0.00). Site 8, at its confluence with South Branch French Creek, fell outside the 95% simultaneous confidence intervals, with a loading rate higher than expected.

Total dissolved solids (TDS)

Sub-basins

Total dissolved solids loading rates are illustrated in Figure 14. Total dissolved solid loading rates into the system were high in both the spring and the summer rain events, although different sub-basins were the major known contributors at each sampling event. The highest total dissolved solids loading rates occurred during the spring rain event, with a mean of 399.55 g/s (79.67, 719.43). Site 67 on Watson Run in Conneaut Outlet had a total dissolved solids loading rate above the 95% confidence interval (1252.17g/s). During the summer rain event, the mean total dissolved solids-loading rate was 218.98 g/s (41.07, 396.89). During base flow, the mean total dissolved solids-loading rate was 31.31g/s (11.85, 50.78). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average nutrient loading rates during base flow. Site 13 and site 103 also had above average nutrient loading rates during the summer rain event.

We found a significant linear relationship, as discharge increases, base flow TDS loading-rates increase (p-value =0.00). Three sites fell outside our 95% simultaneous confidence intervals for TDS loading rates; site 103, at the mouth of Sugar Creek, and site 49 on Woodcock Creek both had lower than expected TDS loading rates, while Watson Run (site 67) had higher than expected TDS loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow TDS loading rates increase (p-value=0.00). None of the sites fell outside of the 95% simultaneous confidence intervals for base flow TDS loading rates.

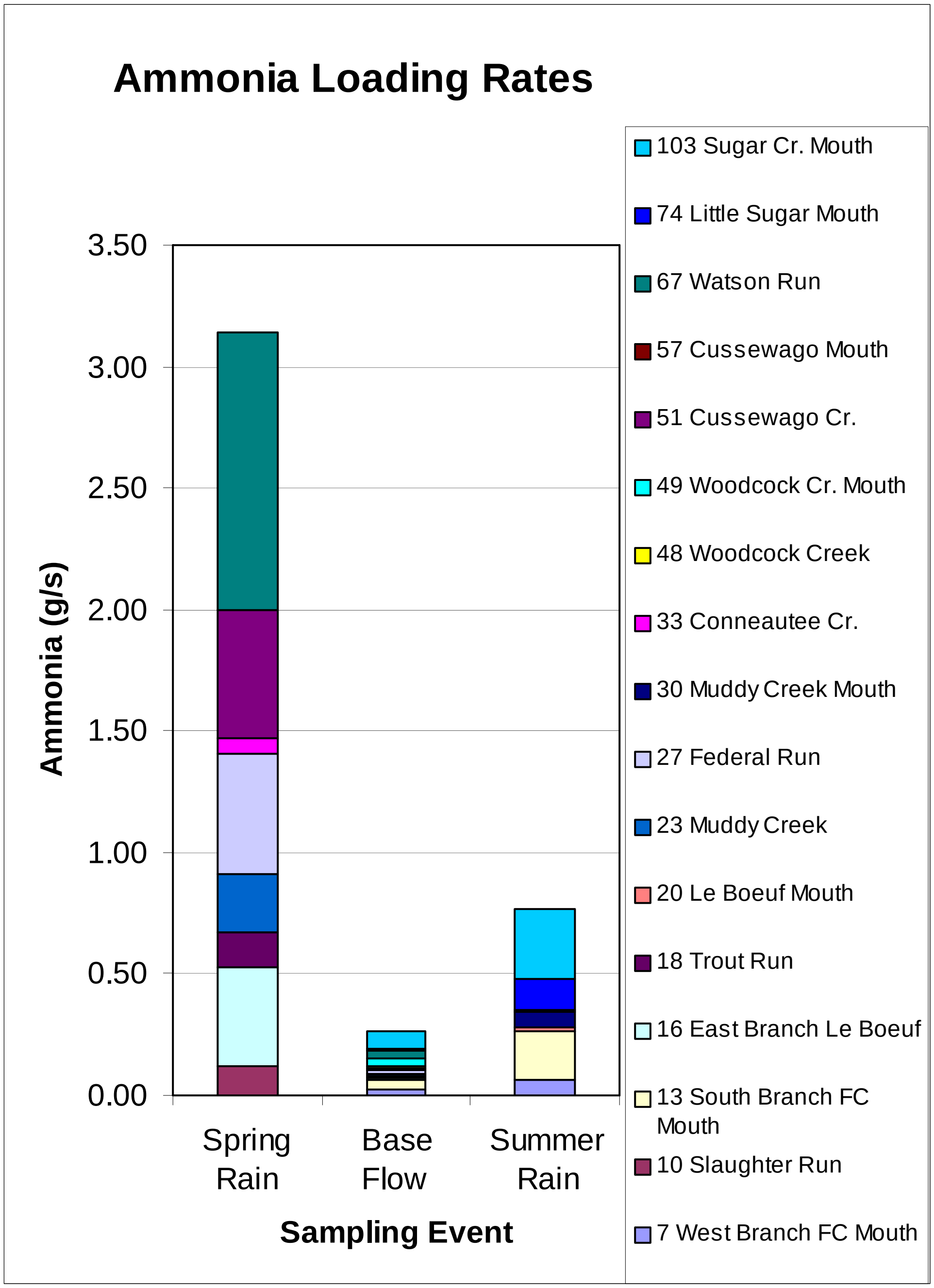


Figure 12: Ammonia loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

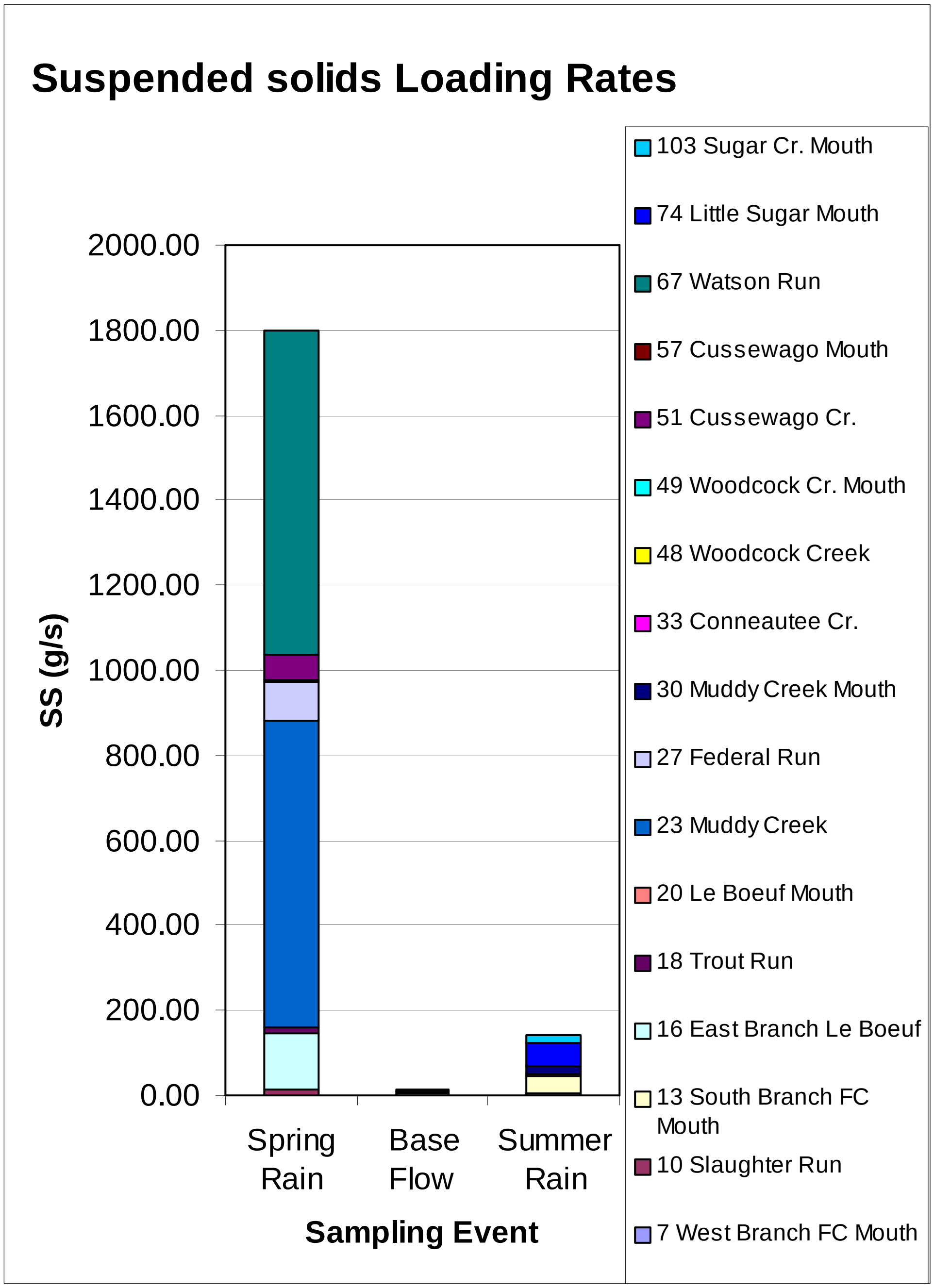


Figure 13: Suspended solids loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

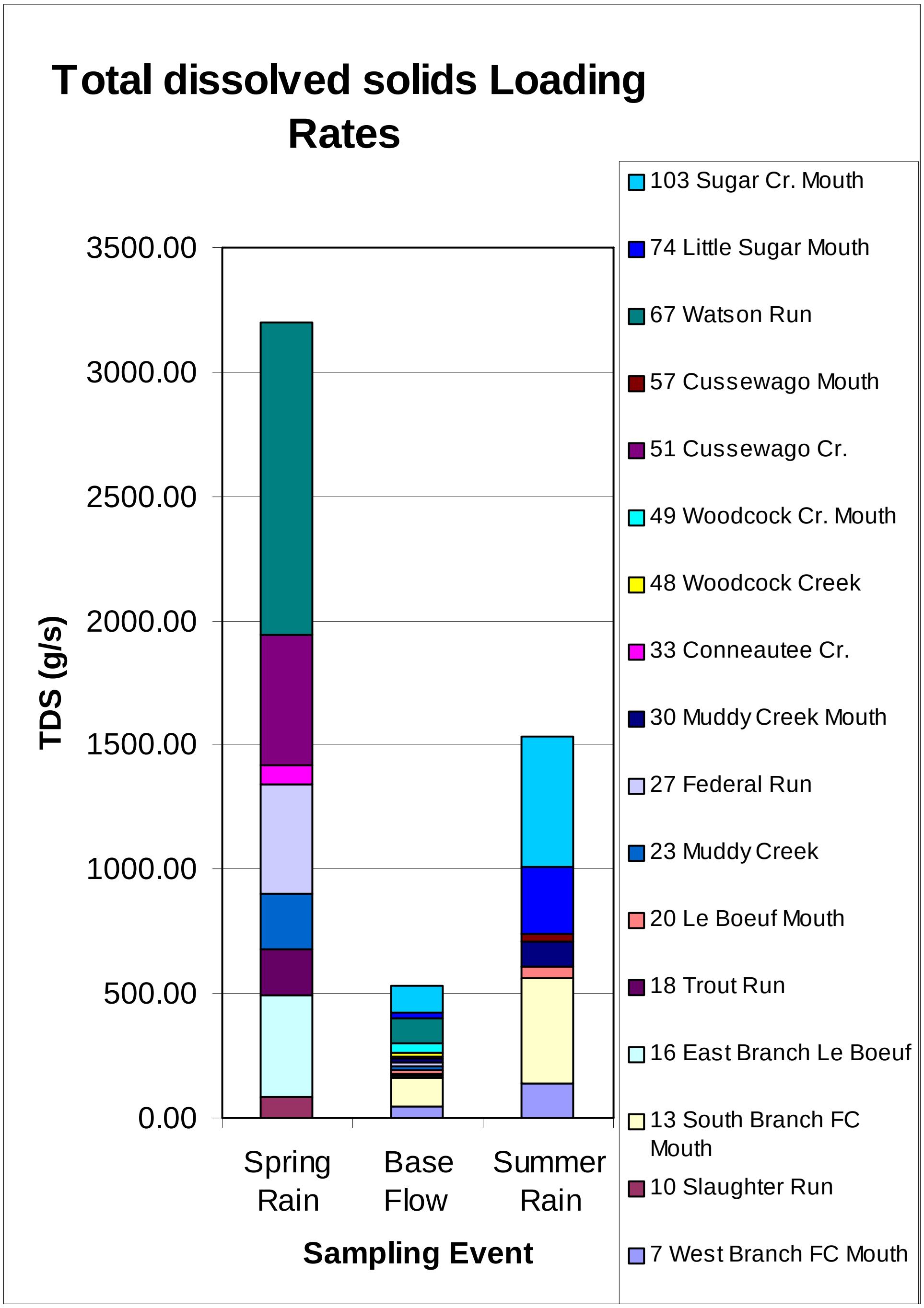


Figure 14: Total dissolved solids loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

Organic Nitrogen

Sub-basins

Organic nitrogen loading rates are illustrated in Figure 15. The highest organic nitrogen loading rates occurred during the spring rain event, with a mean of 3.55 g/s (0.57, 6.52). East Branch Le Boeuf Creek (site 16) and Cussewago Creek (site 51) had organic nitrogen loading rates above the 95% confidence interval. During the summer rain event, the mean organic nitrogen-loading rate was 0.51 g/s (0,1.12). During base flow, the mean organic nitrogen-loading rate was 0.08 g/s (0.02, 0.15). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average organic nitrogen loading rates during base flow. Site 7, near the mouth of West Branch French Creek had an above average suspended solid loading rate during the summer rain-sampling event.

We found a significant linear relationship, as discharge increases, base flow organic nitrogen loading-rates increase (p-value =0.00). Several sites fell outside the 95% simultaneous confidence intervals for expected N loading rates Muddy Creek (site 23) and the mouth of Woodcock Creek (site 49) had organic nitrogen loading rates lower than expected. East Branch of Le Boeuf Creek (site 16) and Federal Run on Muddy Creek (site 27) both had higher than expected organic nitrogen loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow organic nitrogen loading rates increase (p-value =0.00). Two of the sites fell outside of the 95% simultaneous confidence intervals for TDS loading rates; site 47 at its confluence with Woodcock Creek, and site 78 at Utica both had lower than expected organic nitrogen loading rates.

Nutrient contribution

Next we wanted to determine which sub-basins were contributing the most nutrients per unit area into French Creek. We calculated the rate of nutrient loading rates per day per acre for g/day/acre for eight of the sub-basins by dividing the loading rates at the mouths of each sub-basin by the total area of the sub-basin in acres. To test if sub-basin means were different from the overall mean, we compared 95% confidence intervals. First, we calculated the overall mean and 95% confidence interval (denoted by two numbers in parenthesis following the mean) for each parameter using all the data for each of the 8 sub-basins. If the sub-basin mean did not fall within the overall 95% confidence interval, there is significant difference at the $\alpha = 0.05$ level (Table 12). These analyses give us a good picture of which sub-basins are outliers compared to what was typically observed for the whole. Because measurements we were unable to take measurements at the mouths during the spring rain event, we were only able to calculate these rates for the base flow and summer rain events. We were unable to calculate these rates for Conneaut and Conneauttee sub-basins, so they were kept out of this analysis.

Two sub-basins stood out with the most nutrient contributions into the system; South Branch French Creek and Little Sugar Creek. South Branch French Creek contributes a significantly high amount of nitrogen and phosphorus, during both the base flow and summer rain events. During the summer, South Branch had a significantly higher contribution of ammonia. South Branch also had high contributions of total dissolved solids, organic nitrogen and kjeldahl nitrogen during the base flow event. Little Sugar

Creek had significantly high contributions of phosphorus, ammonia, total dissolved solids, organic nitrogen, kjeldahl nitrogen, and suspended solids during the summer rain event.

Table 12: Nutrient loading rates per unit area (g/day/acre) of 8 sub-basins. Bolded type indicates values significantly higher than the overall mean at the α = 0.05 level.

		Woodcock	Little Sugar	West Branch	Le Boeuf	Muddy	South Branch	Cussewago	Sugar Creek	Mean
N, nitrate + nitrite	Base	0.00132	0.00213	**0.00703**	0.00248	0.00000	**0.00709**	0.00023	**0.00644**	0.003340
(g/day/acre)	Summer	NA	0.02940	0.02232	0.00496	0.00089	**0.04500**	0.00092	0.02909	0.016573
P, total	Base	0.00044	0.00043	0.00041	0.00000	0.00030	**0.00136**	0.00000	0.00054	0.000435
(g/day/acre)	Summer	NA	**0.00554**	0.00124	0.00071	0.00178	**0.00818**	0.00023	0.00188	0.002445
N, kjeldahl	Base	0.00751	0.00426	0.00992	0.00213	0.00207	**0.01364**	0.00069	**0.01314**	0.006670
(g/day/acre)	Summer	NA	**0.07245**	**0.09424**	0.00567	0.01302	0.05482	0.00368	0.02722	0.033888
TDS	Base	1.46182	0.91494	1.76943	0.47204	0.43581	**3.12769**	0.10013	1.49845	1.22254
(g/day/acre)	Summer	NA	**11.7075**	5.70673	1.61564	3.14775	**11.4986**	0.58789	6.98373	5.15599
SS	Base	**0.06095**	0.02685	0.03927	0.01134	0.02308	**0.05209**	0.00414	0.04679	0.033064
(g/day/acre)	Summer	NA	**2.45290**	0.17359	0.12652	0.50002	1.14984	0.02670	0.19399	0.57795
N, ammonia	Base	0.00132	**0.00043**	**0.00083**	**0.00035**	**0.00030**	0.00109	0.00000	0.00094	0.000338
(g/day/acre)	Summer	NA	**0.00554**	0.00248	0.00071	0.00178	**0.00545**	0.00023	0.00389	0.002510
N, organic	Base	0.00442	0.00213	0.00289	-0.00035	0.00207	**0.00655**	0.00046	**0.00670**	0.003109
(g/day/acre)	Summer	NA	**0.04304**	**0.07192**	0.00071	0.01302	0.00982	0.00276	-0.00188	0.017424

Discussion of Results

Even though we did not sample the same sites throughout all three time periods, our analyses show comparatively higher rates of nutrients and pollutants being washed into the system during the spring rain event. Springtime plowing and application of fertilizers to agricultural fields are likely the cause of these increased nutrient levels. Several studies have attributed much of the increased nutrient levels in surface and groundwater to applications of commercial fertilizers, manures or other nutrient sources (Mason et al. 1990, Omernik et al. 1981). In addition, physical alteration to the land surface due to agriculture can also cause detrimental effects on water quality. Plowing exposes unstable topsoil to the effects of weathering, while compaction by grazing animals and machinery may lower infiltration rates, thereby promoting runoff. Furthermore, agricultural land has less developed root systems than forested land, which may lead to a reduced capacity to retain nutrients (Wood 1994).

The only nutrient that had somewhat similar loading rates during the spring and summer rain was nitrogen (nitrate + nitrite). As stated in water quality discussion, acid rain may be a significant source of nitrogen during this time period.

One site on the main-stem of French Creek fell outside of what was expected for nutrient loading rates, site 61 just below Meadville. Meadville is the most heavily populated urban area in the watershed, with approximately 13,000 people. High sediment and nutrient loading may be due to any number of factors associated with an urban environment, such as road runoff, sewage, and industrial discharge.

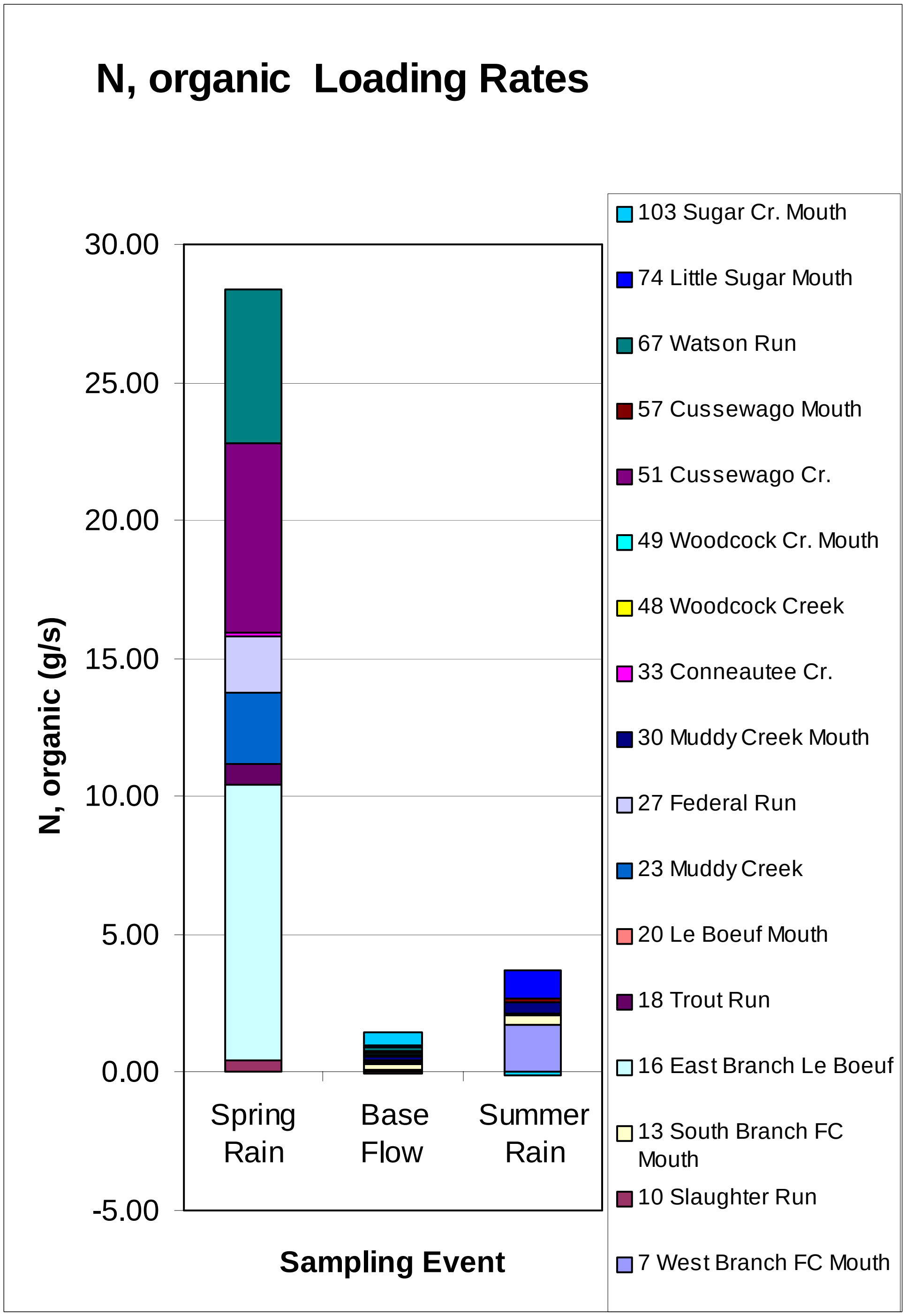


Figure 15: Organic nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

Relationships between macroinvertebrates and land-use, water quality and habitat

Analysis and Results

Because we found some significant differences in habitat, water quality and macroinvertebrate metrics between sub-basins and sites, we wanted to examine the relationships between macroinvertebrates and environmental parameters.

Land-use

On the sub-basin level, we tested the correlation of percent EPT and percent Diptera to percent agriculture and percent forest using standard Pearson correlation methods (Mathsoft 1999). Although the correlations were not significant to the p=0.05 level, we did observe trends among the data. There is a negative relationship between percent agriculture and percent EPT taxa (r = -0.578). So as percent agricultural land increases, percent EPT taxa decreases. There is a positive relationship between percent agriculture and percent diptera (r = 0.470) and a negative relationship between percent forest and percent diptera (r = -0.444). Figures 16 and 17 illustrate these trends.

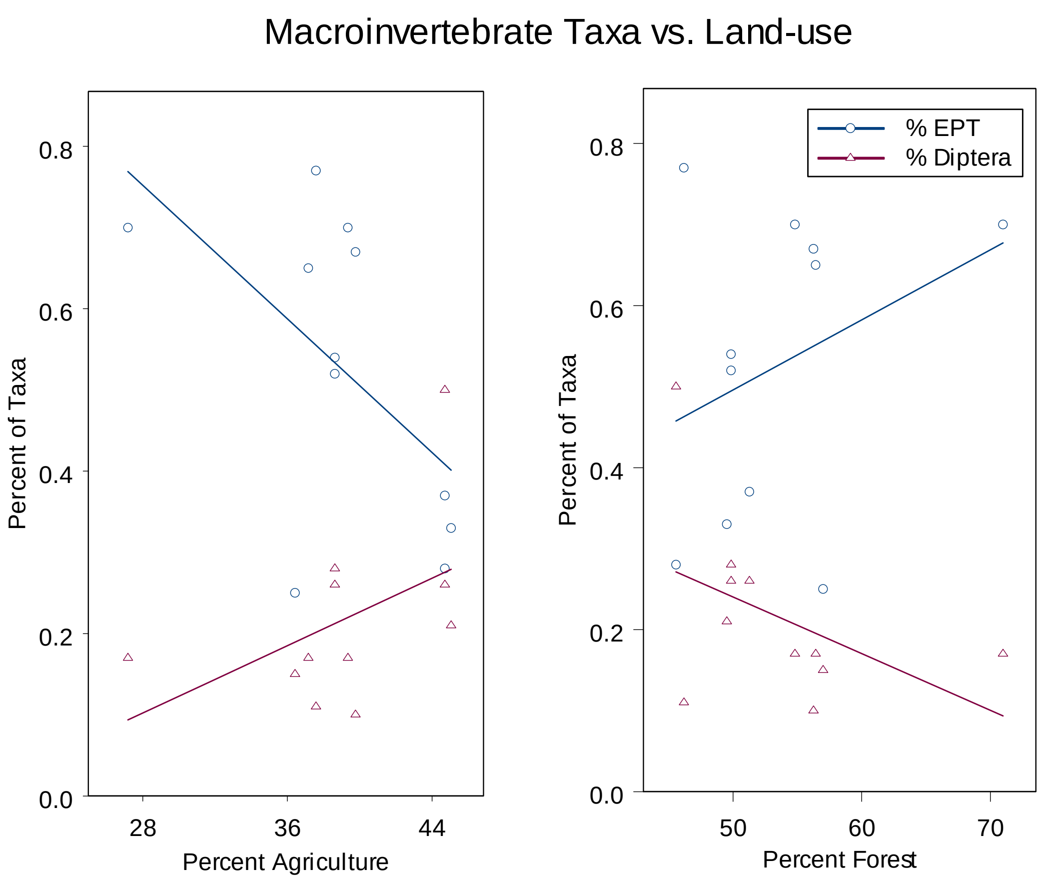
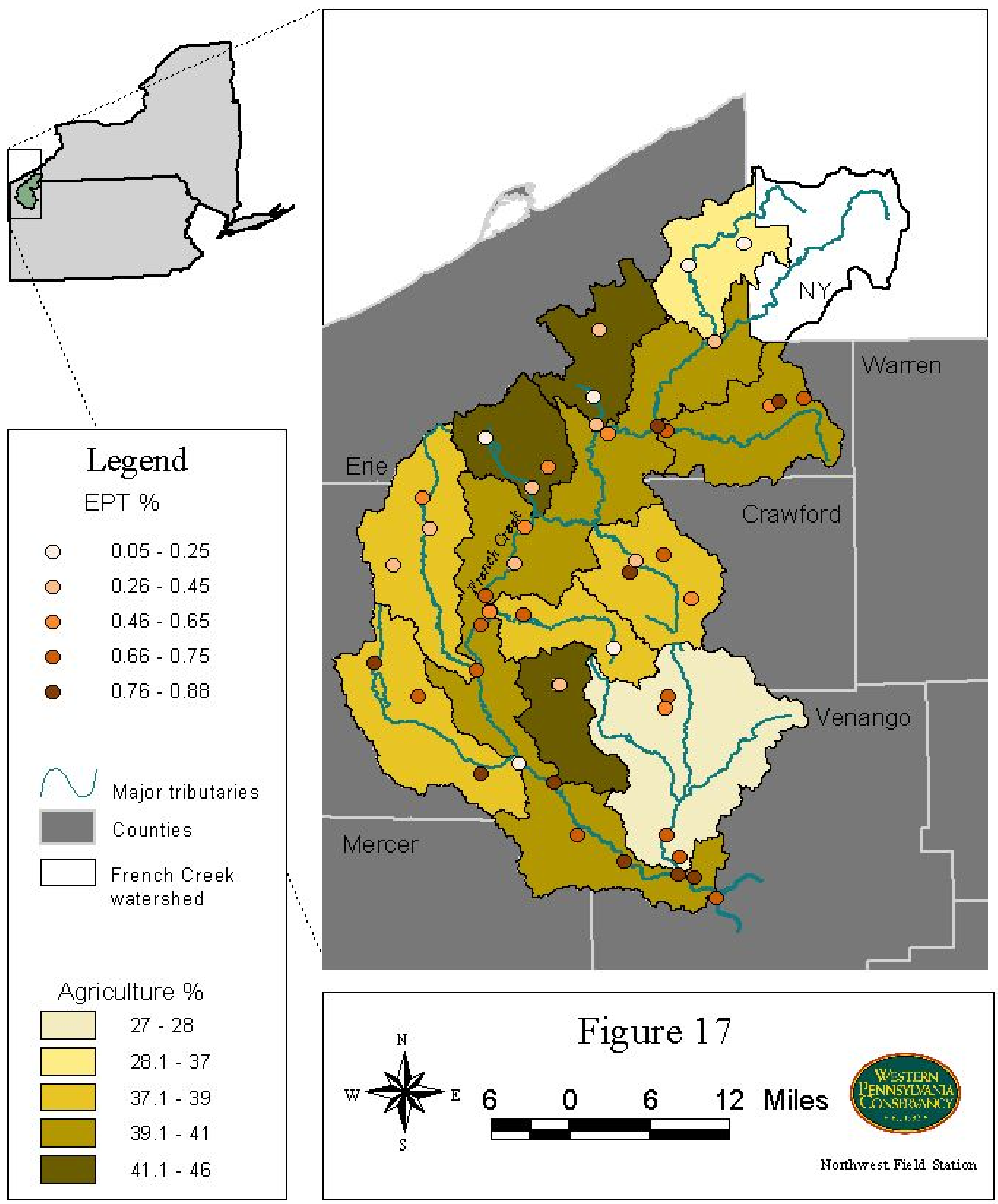


Figure 16: Percent EPT taxa and percent Diptera vs. percent agriculture and percent forest.

Figure 17: Percent EPT versus percent agriculture in the French Creek watershed



We tested the correlation of taxa richness and macroinvertebrate composition measures to water quality or habitat parameters using Kendall's rank-based correlation methods. For each test, we used two-sided alternative hypothesis that $\rho \neq 0$, where ρ is the (population) correlation coefficient parameter. Significance was assessed at the $\alpha = 0.05$ level. If $\rho > 0$, then there is a positive correlation, if $\rho < 0$, there is a negative correlation. Kendall's method is based on ranks, and therefore not so sensitive to outliers and non-normality as the standard Pearson estimate (Mathsoft 1999). Kendall's rank correlation measures whether the macroinvertebrate metric increases or decreases with a given water quality or habitat parameter even when the relationship between the two is not necessarily linear (Ott 1993). Significant (p-value<0.05) responses of taxa richness or composition measures to increasing water quality or habitat parameter are given in Table 13. Discussion of each significant parameter follows.

Habitat/Riparian

Habitat/riparian score 1 was positively correlated with percent EPT taxa, number of Ephemeroptera, number of Plecoptera and total number of EPT taxa. Habitat/riparian score 2 was positively correlated with taxa richness, number of Plecoptera and total number of EPT taxa. Total habitat/riparian score was positively correlated with number of Plecoptera and total number of EPT taxa. Habitat/riparian score 2 and total riparian score were both negatively correlated with HBI scores. As total habitat/riparian score increases, HBI score decreases. This strong relationship is partly due to the habitat/riparian score 2; HBI decreased with increasing habitat/riparian 2 score.

Total Phosphorus

We found a significant relationship between total phosphorus in the spring rain and base flow events and percent Diptera. As total phosphorus increases, percent Diptera increases.

Organic Nitrogen

We found a significant relationship between organic nitrogen and percent Diptera. During the spring rain event, percent Diptera showed increasing trends with increased organic nitrogen.

Kjeldahl nitrogen

There is a significant relationship between kjeldahl nitrogen and number of Ephemeroptera during base flow, Ephemeroptera decreasing with increased kjeldahl nitrogen concentrations.

Total Dissolved Solids (TDS)

There was a significant relationship between spring rain TDS concentrations and taxa richness, number of Plecoptera, and number of EPT taxa. All of these metrics decreased with increased TDS concentrations. During the base flow percent EPT decreased with increasing TDS. Number of Ephemeroptera showed decreasing trends with increasing TDS concentrations during the summer rain event. HBI score showed increasing trends with increasing TDS during the spring rain and base flow.

Table 13: Significant (p<0.05) response of taxa richness or composition measures to increasing water quality or habitat parameter. Correlations for %EPT and % Diptera were made using all data. Kendall's rank correlation methods were used for the remaining macroinvertebrate metrics using the data from the 19 sub-sampled sites.

		% EPT	% Diptera	HBI	Taxa Richness (Genus Level)	% Chironomidae	No. Ephemeroptera Taxa (Genus Level)	No. Plecoptera Taxa (Genus Level)	No. Tricoptera Taxa (Genus Level)	No. EPT Taxa (Genus Level)
Habitat/ Riparian Scores	Score1	Increase					Increase	Increase		Increase
	Score2			Decrease	Increase			Increase		Increase
	Total			Decrease				Increase		Increase
P, total (mg/L)	Spring		Increase							
	Base		Increase							
	Summer									
N, organic (mg/L)	Spring		Increase							
	Base									
	Summer									
N, kjeldahl (mg/L)	Spring									
	Base									
	Summer						Decrease			
TDS (mg/L)	Spring			Increase	Decrease			Decrease		Decrease
	Base	Decrease		Increase						
	Summer						Decrease			
Conductivity (mS/cm)	Spring		Increase							
	Base									
	Summer									
Salinity (ppt)	Spring									
	Base							Decrease		
	Summer									
DO (%)	Spring									
	Base	Decrease							Decrease	
	Summer									
DO (mg/L)	Spring									
	Base	Decrease							Decrease	
	Summer									
pH	Spring									
	Base	Increase								
	Summer		Decrease							

Conductivity

We found a significant correlation between % Diptera and conductivity during the spring rain event. As conductivity increased, we saw an increase of % Diptera.

Salinity

We found a significant correlation between number of Plecoptera taxa and base flow salinity levels. As salinity increases, the number of Plecoptera taxa decreases.

Dissolved Oxygen

We found significant correlation between %EPT and DO % during base flow. As DO saturation increases, %EPT increases. We found a similar relationship between number of Tricoptera and DO % during base flow. We found significant correlations between dissolved oxygen concentrations and the same metrics as above.

pH

We found a significant correlation between percent EPT and pH, which showed an increase with increasing pH. We found a significant correlation between percent Diptera and pH. Percent Diptera showed a decreasing trend with increasing pH during the summer rain event.

Discussion of Results

Several studies have recognized relationships between land use and water quality with macroinvertebrate communities (Barbour et al. 1994, Barbour et al. 1996, DeShon 1995, Fore et al. 1996, Smith and Voshell 1997). These studies show that total number of taxa, EPT taxa, Ephemeroptera, Plecoptera, and Tricoptera are all expected to decrease with increased perturbation. Similarly, percent EPT taxa, Ephemeroptera, Plecoptera, and Tricoptera are expected to decrease with increasing disturbance. Percent Diptera and percent Chironomidae increase with increasing disturbance. Additionally, HBI is expected to increase with increasing disturbance (organic pollution) (Barbour et al. 1992, Kerans and Karr 1994).

Our study concurs with other studies, trends in our data show that as habitat/riparian and water quality was more degraded, number and percentage of EPT taxa decreased, while percentages of diptera and chironomids increased. Our study made the assumption that water quality was identical throughout the sampled reach. Although we found no significant correlations between macroinvertebrates and nitrogen (nitrate + nitrite), BOD, suspended solids, ammonia, or temperature, we did see trends in our data that indicate some of these and other parameters may need to be studied in finer detail on a microhabitat level.

Macroinvertebrates can readily drift to new acceptable microhabitats. On the other hand other aquatic organisms, such as freshwater mussels, cannot as easily choose their immediate environment.

RELATIONSHIPS BETWEEN WATER QUALITY, LAND-USE, AND HABITAT

Analysis and Results

In this section we examine the relationships between water quality and habitat parameters. For data available at the sub-basin level (percent agriculture and percent forest), we tested the correlations using standard Pearson correlation methods (Mathsoft 1999). We tested the correlation of the remaining water quality and habitat parameters using Kendall's rank-based correlation methods as described in the previous. For each test, we used two-sided alternative hypothesis that $\rho \neq 0$, where ρ is the (population) correlation coefficient parameter. Significance was assessed at the $\alpha = 0.05$ level. If $\rho > 0$, then there is a positive correlation, if $\rho < 0$, there is a negative correlation (Ott 1993). Discussion of each significant parameter follows.

Riparian/Habitat Score 1

Spring rain

TDS concentrations were significantly negatively correlated with habitat/riparian score (p-value=0.034). TDS concentrations decrease as habitat/riparian score 1 increases.

Base flow

N, kjeldahl concentrations were negatively correlated with habitat/riparian score 1 (p-value =0.032). TDS concentrations were negatively correlated with habitat/riparian score 1 (p-value = 0.0085). As habitat/riparian scores increase, TDS and kjeldahl nitrogen concentrations decrease.

Riparian/Habitat Score 2

Base flow

Kjeldahl nitrogen and total dissolved solid concentrations were both negatively correlated to riparian/habitat score 2 (Nkj p-value = 0.020, TDS p-value = 0.049). As riparian/habitat score 2 increases, we see a significant decrease in kjeldahl nitrogen and total dissolved solid concentrations. Phosphorus and habitat/riparian 2 had a positive correlation (p-value = 0.031). We found no significant correlations between riparian score 2 and nutrient loading rates, temperature, conductivity, dissolved oxygen or pH.

Percent Agriculture

Spring rain

We found a significant positive correlation between pH and percent agriculture (p-value = 0.020). As the percent agriculture increases, so does pH.

Base flow

As percent agriculture increases, percent forested land decreases (p-value = 0.003). Habitat/riparian score 1 and percent agriculture are negatively correlated (p-value = 0.021). As percent agriculture increases, we see decrease in habitat/riparian score 1. Similarly, we found a significantly strong negative correlation between percent agriculture and total habitat/riparian score (p-value = 0.016), so as percent agriculture increases, total riparian/habitat score decreases.

Summer rain

We found a significant positive correlation between conductivity and percent agriculture (p-value =0.0488). As the percentage of agriculture rises, so does conductivity.

Percent Forest

Base flow

Habitat/riparian scores 1 and 2 are both positively correlated to percent forest (Score 1 p-value = 0.021, Score 2 p-value = 0.037). Dissolved oxygen concentrations and pH are also both positively correlated to percent forest (DO p-value = 0.0423, pH p-value = 0.0423). As the percentage of forested land in the sub-basin increases, so does dissolved oxygen, pH and both habitat/riparian scores.

Summer rain

Dissolved oxygen concentration is significantly positively correlated to percent forest (p-value = 0.0049). As the percentage of forested land increases, so does dissolved oxygen concentrations.

Discussion of Results

Several studies have established relationships between land use and water quality, with a general consensus that the more intense the land is used, the more adverse the effects are upon water quality (Byron and Goldman 1989, Burkart and Kolpin 1993). As discussed in the water quality section of this report, agriculture increases erosion and nutrient input into streams. Furthermore, studies show that watersheds with less forested area tend to have unbalanced flow regimes marked by increased flooding and storm runoff (Kostadinov and Mitrovic 1994). Increased frequency and intensity of flooding and runoff events increases erosion, washing suspended solids and nutrients into the streams. In our study, we found that habitat and riparian scores are correlated to land-use, nutrient concentrations and sedimentation. As a rule, trends in our data show that as habitat/riparian scores got worse, nutrient and sedimentation increased. The only exception to that rule was base flow phosphorus, which increased in concentrations with increasing habitat/riparian score 2.

Several studies discuss the benefits of healthy riparian buffers (Barton et al. 1985, Gregory, et al. 1991, Naiman et al.1993). Riparian zones are crucial to stream health by filtering excess nutrient and sediment runoff, preventing erosion, and providing cooling shade and habitat for organisms.

PRIORITY AREAS

Now that we have examined water quality, in-stream and riparian habitat and macroinvertebrate communities more closely, we can more accurately prioritize potential problem areas within the French Creek watershed (Table 14). With increased stream or habitat degradation, some parameters (e.g. nitrogen, total-dissolved solids, suspended solids, etc.) increase. Other parameters such as dissolved oxygen concentration, decrease with increasing degradation. Table 14 is an adaptation of Tables 5 and 6 from our results. For parameters that as a rule increase with increased degradation, we noted sub-basins with significantly higher mean than the overall mean. For parameters that decrease with increased degradation, we noted sub-basins with significantly lower means than the overall mean. Therefore, check marks in Table 14 indicate that the mean values for that watershed were significantly "of poorer quality" than the mean for all the sampled sites.

From our analyses we are able to reveal four sub-basins that stand out as potential problem areas in the watershed; Le Boeuf, Conneauttee, West Branch French Creek, and Conneaut. Those four sub-basins should be considered as high priority areas for monitoring and restoration efforts.

Le Boeuf Creek

High levels of nitrogen and total dissolved solids during the spring rain event, suggest agricultural practices play a significant role in water quality in the Le Boeuf Creek sub-basin. Le Boeuf Creek has significantly higher than average percent agriculture and significantly lower than average percent forested land. Le Boeuf Creek watershed also has several golf courses within its boundaries, which may also be significant contributors of nutrients into the system. Nutrient levels in Lake Le Boeuf are high (Wellington, personal communication) and may be a contributing factor as well, especially in the spring after lake turnover. A comprehensive watershed assessment for Lake Le Boeuf would benefit restoration efforts in the Le Boeuf sub-basin. Habitat/riparian scores in the Le Boeuf Creek sub-basin were significantly lower than the watershed mean. Trout Run had particularly low scores, showing problems with all aspects of the assessed habitat.

The significance of Le Boeuf Creek as the highest priority area identified through this study is further underscored by the sub-basin's importance for the Endangered clubshell, *Pleurobema clava*. Investigations by WPC scientists have identified the clubshell as having a limited range in the French Creek watershed. From the mainstem of French Creek, it is only common upstream of the confluence with Muddy Creek and extends upstream to the confluence with Le Boeuf Creek. It is also known from Le Boeuf Creek, Muddy Creek, and Conneaut Outlet.

West Branch French Creek

Although West Branch French Creek had an average percentage of agricultural and forested land for the French Creek watershed, it still stood out as a potential problem area. Study sites on the West Branch of French Creek had particularly low in-stream habitat and riparian scores. The West Branch French Creek originates in New York, where pollution and sediment sources may exist, but were beyond the scope of this study. High levels of phosphorus and total dissolved solid concentrations during the spring, for example, may be attributed to agricultural inputs from New York.

Table 14: Potential problem areas within the major sub-basins of French Creek.

		Conneaut	**Conneauttee**	**Cussewago**	*French Creek*	**Le Boeuf**	**Little Sugar**	**Muddy**	**South Branch**	**Sugar**	**West Branch**	**Woodcock**
Land-use	% Agriculture		x			x	x					
	% Forest	x				x						
DEP Habitat/Riparian	Score1					x	x				x	
	Score2	x		x		x					x	
	Total Riparian		x	x		x	x				x	
Macroinvertebrate	% EPT		x			x	x				x	
	% Diptera			x		x	x					x
N, nitrate + nitrite (mg/L)	Spring		x		x		x	x	x			
	Base		x									
	Summer		x						x	x	x	
P, total (mg/L)	Spring						x				x	x
	Base		x									
	Summer	x	x			x	x		x			
N, kjeldahl (mg/L)	Spring											
	Base	x									x	
	Summer	x										
TDS (mg/L)	Spring	x	x		x	x			x		x	
	Base	x	x						x		x	
	Summer		x	x		x			x		x	
SS (mg/L)	Spring							x				x
	Base											
	Summer	x					x	x				x
BOD (mg/L)	Spring											
	Base								x			
	Summer											
N, organic (mg/L)	Spring							x		x		
	Base	x		x		x		x			x	
	Summer	x									x	
Temperature (˚ C)	Spring	x				x	x			x		
	Base				x				x		x	x
	Summer			x	x							x
Specific Cond. (mS/cm)	Spring		x			x						
	Base	x	x			x					x	
	Summer		x			x					x	
Conductivity (mS/cm)	Spring		x			x					x	
	Base	x	x		x	x			x		x	
	Summer		x			x					x	
Salinity (ppt)	Spring		x			x					x	
	Base	x	x			x					x	
	Summer		x								x	
DO (%)	Spring											
	Base	x		x								
	Summer	x				x						
Total Poor Quality Indicators		16	20	7	5	21	10	5	9	3	21	6

Conneauttee Creek

High nutrient levels and sediment loads, particularly during the spring rain, at sites in Conneauttee Creek suggest agricultural practices play a significant role in water quality in this sub-basin. During the spring rain, sites in the Conneauttee sub-basin had high concentrations of nitrogen and total dissolved solids. Salinity and conductivity were high as well. Conneauttee sub-basin has a significantly higher than average percent agriculture. Total habitat/riparian score in Conneauttee sub-basin was significantly lower than the watershed average. Because the Conneauttee sub-basin is extensively farmed, it has already been targeted by the French Creek Project for agricultural BMP implementation.

Conneaut Outlet

Conneaut sub-basin had significantly lower than average percent forested land. Habitat score 2 was significantly lower than the watershed mean in Conneaut, where thin riparian vegetative zones seen in Watson Creek and Rock Creek in the Conneaut sub-basin contribute to low scores. High nutrient levels in Conneaut Lake may contribute significantly to the Conneaut sub-basin nutrient totals. The Pennsylvania DEP has listed Conneaut Lake as impaired by excessive nutrients. The lake is scheduled for the development of Total Maximum Daily Load (TMDL) restrictions.

Healthy sub-basins

Sugar Creek stood out as the highest quality sub-basin. Sugar Creek was the only sub-basin with significantly lower than average percent agriculture and higher than average percent forested land. Sugar Creek also had higher than average habitat/riparian scores.

Other relatively healthy sub-basins were Muddy Creek, the main-stem of French Creek, and Woodcock Creek. Habitat/riparian scores were significantly higher than the mean in Muddy Creek and Woodcock sub-basins.

Biological monitoring

French Creek has a diverse and seemingly healthy aquatic community. Further study is underway by WPC and partners to examine freshwater mussel distributions, densities, and recruitment. The same study will also examine fish distribution in the watershed, with particular interest in those species that play an essential role in mussel reproduction. The objectives of this study are to determine the present status of unionids in the French Creek watershed and to interpret unionid distributional trends within western Pennsylvania rivers with respect to present habitat, water quality, and fish data. Results of this study will be the subject for the 2nd Annual State of the Stream Report on the Health of French Creek in early 2005. While current efforts are focused on aquatic communities in French Creek proper, similar comprehensive assessments should be conducted throughout the watershed. Western Pennsylvania Conservancy is currently seeking funding for this work. Macroinvertebrate communities should also continue to be monitored at selected sites throughout the watershed. Biological data will be used to develop a monitoring and protection plan for French Creek's aquatic resources and restoration and recovery plans for species of special concern throughout western Pennsylvania.

With many groups inventorying and assessing various components of French Creek's aquatic communities throughout the watershed, a concerted effort should be made to coordinate research findings. The watershed community, scientists, natural resources agencies, and conservation organizations would benefit by an annual symposium of research findings.

Water quality monitoring

Because important parameters such as temperature, nutrient/sediment loads, and dissolved oxygen vary spatially and temporally, we recommend permanent water quality/discharge monitoring stations be installed at the mouths of each major sub-basin and along the main-stem river, particularly above and below urban areas. Proposed meters can provide continuous water quality and turbidity data and allow us to determine sediment loads and their sources. Continuous water quality monitoring should also take place in strategic areas across the watershed, particularly those streams we noted as problem areas. These data will be used to develop a hydrologic model and a water budget for the system. After the sediment and pollution sources are known, we can better address restoration efforts to control any areas of concern.

French Creek Project partners, including The Nature Conservancy and WPC, with the help of county conservation districts and USFWS, are currently planning the installation of 10 such stations at the mouths of the 10 major tributaries to French Creek.

Stream hydrology/geomorphology

Development of a hydrologic budget remains a crucial need for the understanding of the French Creek system and adequate protection of water quantity and aquatic habitat. Through the current mussel/fish project, WPC is working with Edinboro University to continue evaluation of the physical stream characteristics impacting aquatic habitat. This work should be expanded and using Straffin's model project (Appendix A), a comprehensive study of French Creek's hydrology and geomorphology should be undertaken. Special attention should be given to impacts from dam construction at Union City and Woodcock. Additionally, geomorphology, hydrology, and glacial geology data should be interpreted along with freshwater mussel distributional data to assess biogeographical relationships between mussel ranges and physical stream parameters.

Riparian habitat restoration

Because of the significant correlations we found between riparian and in-stream habitat with water quality and macroinvertebrate parameters, we propose efforts be made to restore riparian habitat in the priority areas. In highly agricultural areas, we propose a promotion of agricultural BMPs, restoration of wetlands and riparian buffers, and an increase in stream bank fencing to reduce impacts from livestock. We suggest monitoring restoration efforts with physical stream assessments, including visual assessment of stream channel and riparian areas throughout the watershed. Macroinvertebrate communities should also continue to be monitored at these sites.

Similar restoration efforts should take place in urban and developed areas to restore bank and riparian habitats. Landowners should be educated on watershed issues and restoration practices.

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APPENDIX A

Assessment of the Physical Environment of French Creek, South of Union City Dam.

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OBJECTIVE

The objective of this report is to document the physical environment of a small portion of the French Creek watershed, including the geomorphology, sedimentology, and hydrology of the channel. This report documents basic physical parameters of the stream system in order to provide base-line data that may be used as a reference for future stream monitoring efforts.

BACKGROUND

French Creek is a biologically diverse stream, but it is fragile and subject to environmental degradation. One of the first steps in protecting the stream involves documentation of its biological and physical characteristics, in order to establish baseline data against which future changes can be compared. Comparison of the physical environment and associated biota of a healthy stream also allows us to better understand how that ecosystem works.

The typical parameters incorporated in stream monitoring efforts include: channel cross sectional area and shape, flow velocity, discharge characteristics, bedrock geology, river bed substrate (grain size and sorting), and bank stability/riparian zone descriptions (Harrelson *et al.*, 1994). Changes in these parameters through time can be documented and compared with changes in land-use and other environmental controls, in order to better understand how these variables affect local stream ecology.

In addition to the documentation of the physical stream habitat, an understanding of stream hydrology is also important in understanding basic stream functions. This report incorporates a study of flow variability, based on U.S.G.S gauging station data for French Creek. Stream flow variability is an important aspect in the health of natural stream ecosystems. Past and future impacts on flow variability, such as construction of dams like that at Union City in 1970, or the proposed future alteration of that dam (see www.lrp.usace.army.mil/rec/lakes/unioncit.htm) have, and will likely, impact the stream ecology.

The study site described in this report is located approximately 2 miles downstream from the Union City dam (Figures 1 and 2), in Erie County. The study site includes a natural run and riffle sequence, and a disturbed section, chosen to best represent stream environments typical of French Creek.

General Geology

The bedrock of northwest Pennsylvania is made up of predominantly flat-lying to gentle, southeast dipping sedimentary rocks of marine origin. In the study area, all of the bedrock is of Upper Devonian age (Shepps et al., 1959). Exposed rock units include the Chadakoin and Venango Formations. The Chadakoin Formation (shale and sandstone) is exposed at lower elevations such as valley floors (Figure 3). The Venango Formation overlies the Chadakoin, and makes up the valley walls and hilltops. The Venango Formation consists primarily of sandstone and shale, but also contains coarser, conglomeratic beds (Berg, 1981).

The bedrock of the area has been sculpted by multiple glacial advances and retreats. Glacial deposits of the Union City area are primarily composed of ground moraines associated with the Kent Till, of Wisconsin age. Outwash sand and gravel, found underlying the many Pleistocene terraces of French Creek, partially fills valleys that drained glacial margins, such as French Creek.

The post-glacial (Holocene) evolution of French Creek remains poorly understood, but alluvial terraces along French Creek and associated tributaries attest to down-cutting and sediment removal by the stream since deglaciation. Terraces also provide a record of changing channel morphology and sediment load through time, from braided, bed-load (gravelly) dominated systems during glacial episodes, to meandering, mixed (suspended and bedload) load streams during the Holocene. These distinctly different types of river systems can be easily recognized in the field from their respective deposits. Pleistocene outwash is predominantly stratified gravel and sand, while Holocene meandering river deposits typically include poorly to un-stratified gravel overlain by massive fine sand and silt. Major channel changes from braided to meandering systems are often associated with changing environmental conditions (vegetative cover and storm hydrology) that accompany glacial/interglacial conditions (Straffin and Blum, 2002). Human influences can also significantly affect channel morphology.

Soils

Soils within the study area belong to the Howard-Phelps-Fredon-Halsey soil associations (Erie County Soil Survey, 1991). Soils at lower elevations along the French Creek floodplain vary from silt loams to sandy loams. Fine sand loams are prevalent immediately adjacent to the channel, most likely reflecting localized overbank sand deposition by the river. Silt loams are more common away from the channel, on more distal floodplain settings where finer grained sediments have settled in areas of slower moving water.

Pleistocene glacial outwash terraces are coarser grained, and contain better drained, more gravelly soils than those in the Holocene floodplain setting.

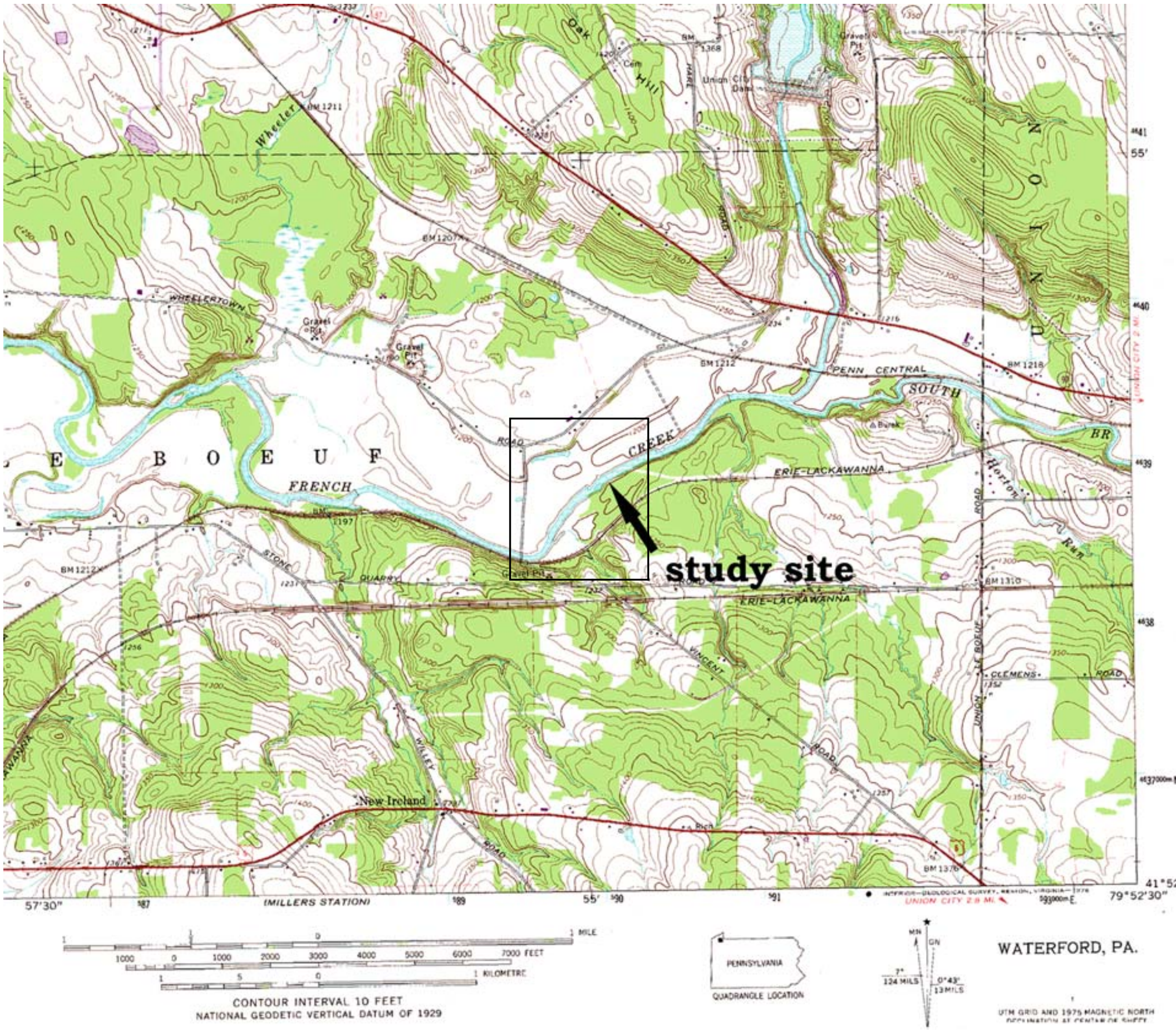


Figure 1. U.S.G.S. topographic map of the study area. Box shows location of aerial photograph shown in Figure 2

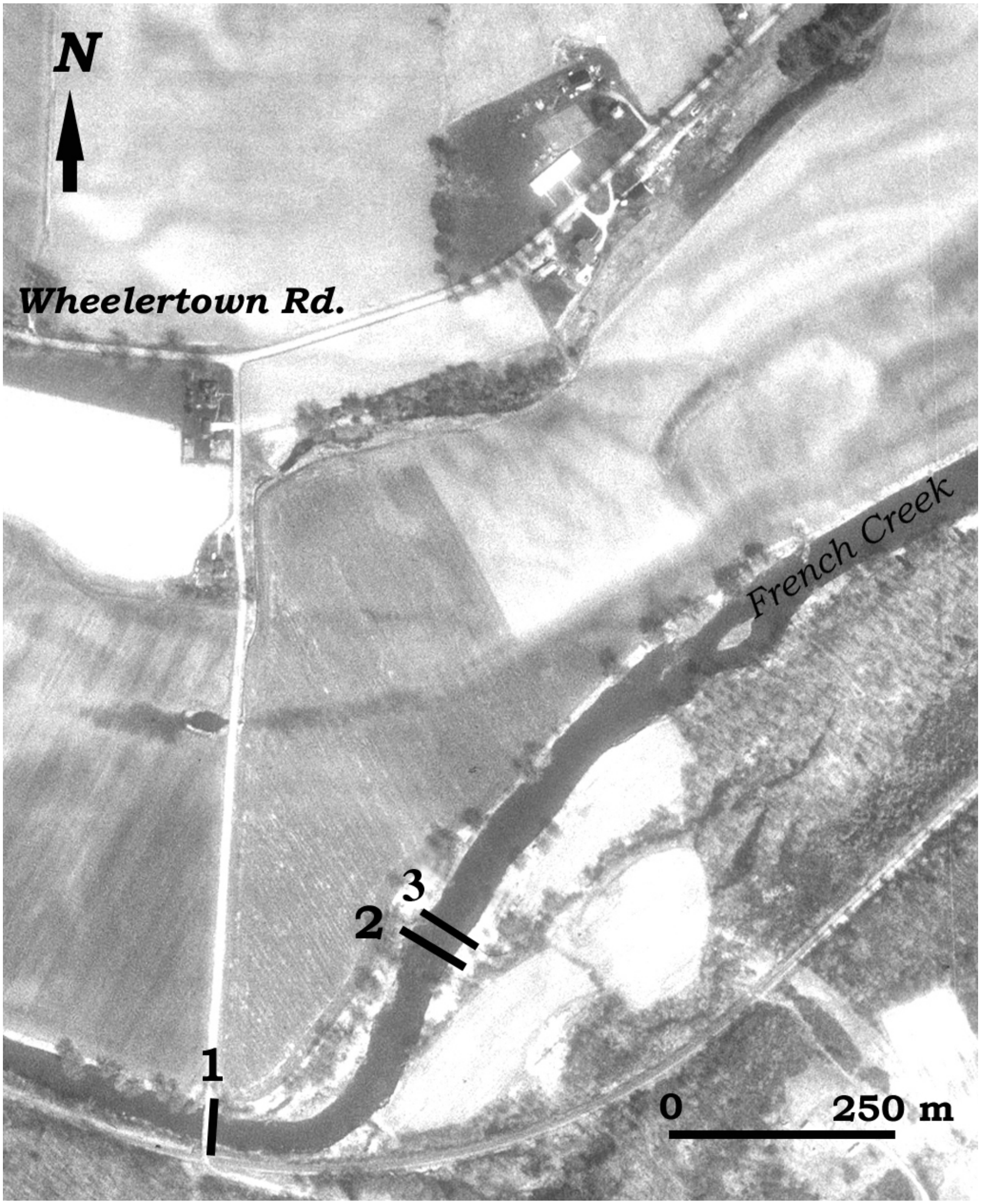
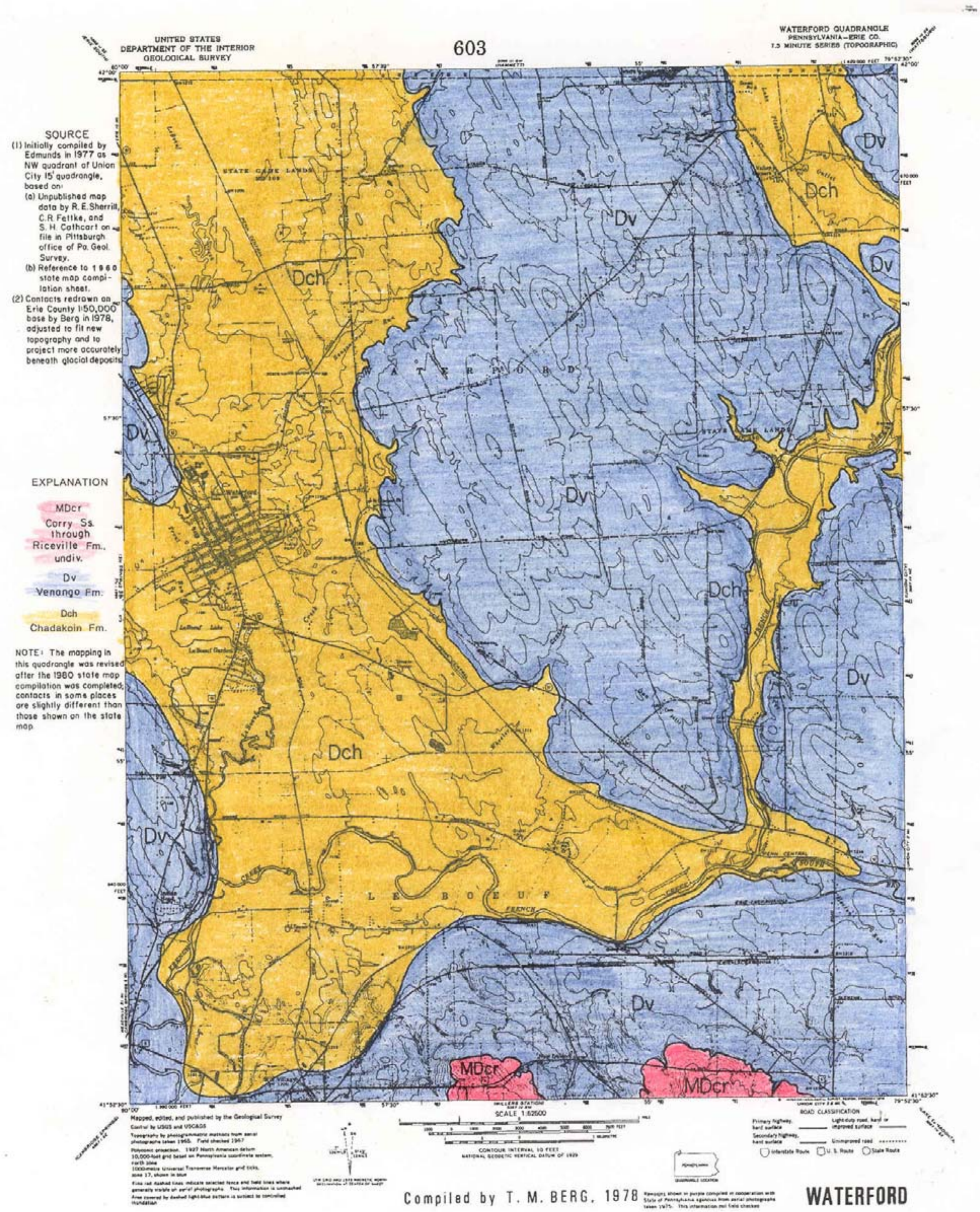


Figure 2. Portion of U.S.G.S. panchromatic aerial orthophotograph showing study site and channel cross section locations.



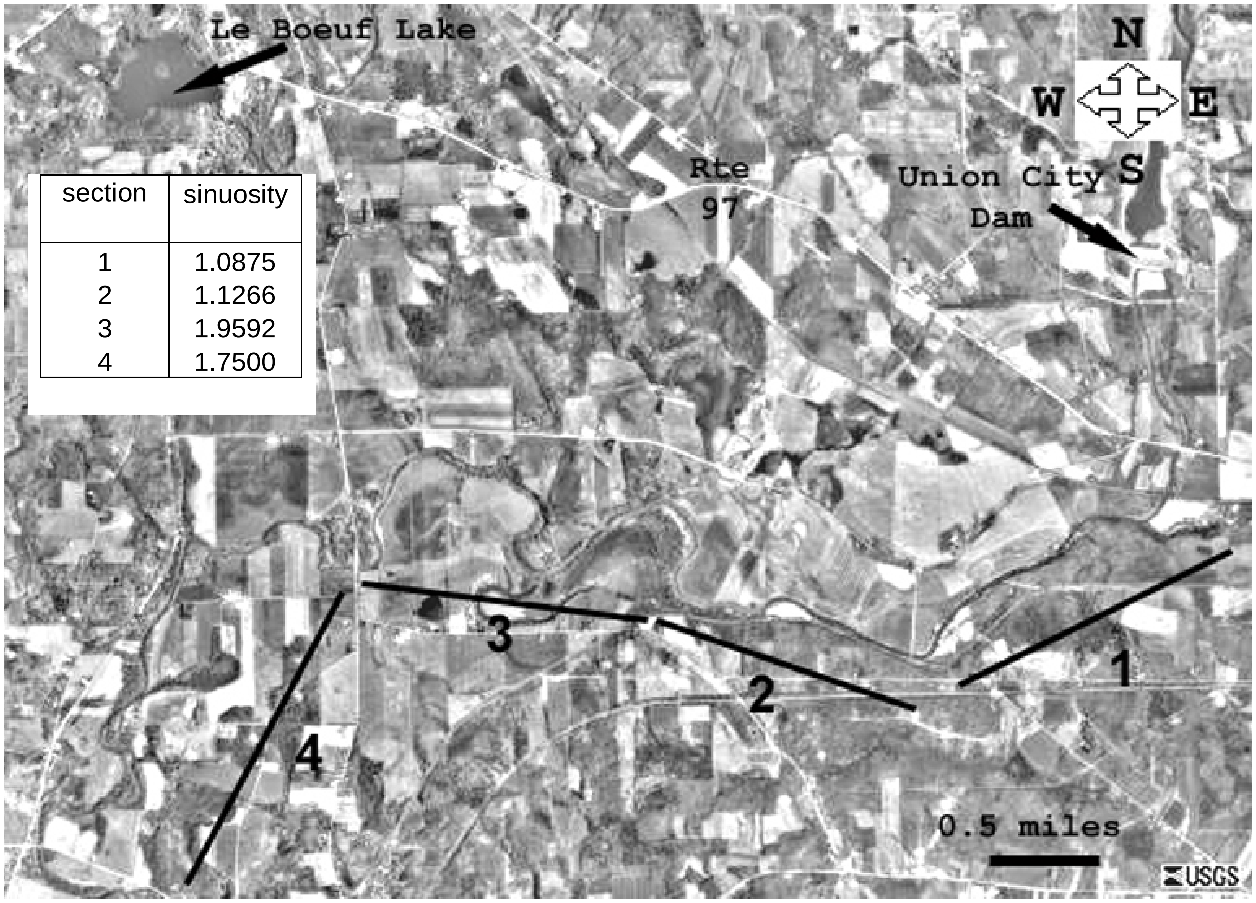
This Map is from Map 61 - Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania
1981 - PA Geological Survey

Figure 3. Bedrock geology of the Waterford area. Study area is indicated by the box.

PHYSICAL CHARACTERIZATION

Channel Morphology

French Creek is generally a single channel, meandering stream. However, the river's morphology varies considerably along its length. For example, sinuosity varies between straight and highly sinuous. The study area documented in this report occurs within a relatively straight reach (section 1, Figure 4).



section	sinuosity
1	1.0875
2	1.1266
3	1.9592
4	1.7500

Figure 4. Variation in sinuosity along French Creek downstream from the Union City Dam. Sinuosity is calculated as channel length divided by reach length (Richards, 1982).

Channel and bank stability is also variable, being in part dependent on the sedimentology of the channel perimeter (Richards, 1982). For example, mixed-load streams such as French Creek typically have floodplains containing predominantly non-cohesive sediments (gravel and sand). These loose sediments do not maintain steep banks, and are easily mobilized during floods, resulting in wide, shallow channels that are prone to lateral migration. Natural zones of bank instability should thus be expected in areas of the valley where there is abundant sand and gravel (such as where the river is cutting through older glacial outwash). Rip-rap or revetment along one side of a channel bank has a similar effect, by armoring the bank and preventing channel widening during floods. During floods, higher flood stages and velocities result from these bank protection efforts, because the channel cannot expand to accommodate the increased discharge. As a result, there is an increased potential for erosion on unprotected

banks opposing revetments. When flood waters recede, areas with gravelly banks will often have wide channels with many channel bars and corresponding riffle sequences.

Areas underlain by glacial till or lacustrine sediments, which have finer, more cohesive sediments, may have more stable channel and bank configurations. As a result, these areas are often the sites of deeper pools.

It is interesting to note the change in sinuosity of French Creek, from a relatively straight channel in the narrow, confined valley below the Union City dam, to the very sinuous channel that meanders through the wide, glacial outwash-filled valley south of Le Boeuf (Figure 4).

Channel Topography and Hydraulic Data

Channel topography was measured with a *Topcon TOTAL* laser transit system, to establish channel geometry at three locations. Channel dimensions were then used to calculate the hydraulic radius for each cross section. Hydraulic radius is a measure of channel efficiency at routing water through the channel. Stream channel cross sections that most closely approximate circular channels are most efficient (larger values), where as wide, shallow streams or deep, narrow channels are less efficient (smaller values). Hydraulic radius thus has important implications for how water interacts with the channel bed and banks.

Flow velocities were measured incrementally at each channel cross section with a *Flow Mate* 2000 flow meter. At the time of measurement (July 2002), river stages (and flow velocities) were very low.

Discharges for the channel were then calculated in a spread sheet, by multiplying velocity by the incremental area of the channel, following the procedures set out by Harellson *et al.*, 1994. Table 1 summarizes the calculated channel dimensions for each of the three cross sections, as measured in July 2002.

Cross section	Low flow channel area (m2)	Calculated discharge (m3/s)	Wetted perimeter (m)	Hydraulic radius (m)
1	16.2	2.8	37.6	0.43
2	22.5	3.1	61.3	0.37
3	14	3.8	51.5	0.27

Table 1. Channel dimensions at three cross section locations. Hydraulic Radius = cross sectional area/wetted perimeter.

Channel Description -Cross Section #1

Cross section #1 was measured at the upstream side of the bridge connecting Wheelertown and Stone Quarry Roads. At this site, the stream hugs the southern valley wall, which is composed of sandstone/conglomeratic bedrock from the Venango Formation, as well as stone rip-rap. Bedrock from the Chadakoin Formation is partially exposed along the channel bottom, and many locally derived boulders are present (see Figure 5). The northern bank of the channel flanks a Holocene terrace and artificial fill around the bridge, which includes gravel and sand. A portion of the bridgeworks and older alluvial deposits are shallowly buried by minor accumulations of recently deposited sand. The natural bank-full elevation is approximately 2 meters above the channel base. Land use surrounding the riparian zone is characterized as urban/row crop, following the classification scheme of Schnier (2002). The riparian/bank zone classification for each channel cross section is summarized in Table 2.

At low flows, water in the channel most resembles a pool, with slow moving water (the average mid-channel velocity at the time of measurement was 0.18 meters per second). The channel width at low flow was 24 meters, and the maximum depth was 0.8 meters (see Figure 6).

The channel geometry is strongly influenced by the constricting nature of the bridge abutments, which are stone, and exposed within the bankfull-stage area of the channel. The channel has a large hydraulic radius, presumably due to flow constriction imposed by the bridgeworks, which promotes channel scouring and sediment removal during high discharges. The bedrock channel base is also resistant to erosion and prevents much scouring during floods.

Cross section #	Riparian Buffer Width	Riparian Vegetation Type	Riparian Vegetation Thickness	Bank Vegetation Type	Bank Vegetation Thickness	Bank Stability
1	Marginal (3)	Good (6)	Excellent (9)	Marginal (3)	Good (6)	Good (7)
2	Marginal (3)	Good (8)	Excellent (9)	Marginal (5)	Excellent (9)	Excellent (9)
3	Marginal (3)	Good (8)	Excellent (9)	Marginal (5)	Excellent (9)	Excellent (9)

Cross section #	Water Pathways	Channel Modification	Shading	In Stream Cover	Embeddedness	Aquatic Vegetation
1	Good (7)	Marginal (4)	Poor (2)	Good (7)	Good (8)	Excellent (8)
2	Excellent (9)	Excellent (10)	Poor (3)	Poor (2)	Good (7)	Good (6)
3	Excellent (9)	Excellent (10)	Poor (3)	Poor (2)	Good (7)	Good (6)

Table 2. Riparian Assessments. Ranking is on a scale of 1-10, following the classification scheme of Schnier (2002).

Figure 5. Photograph of French Creek channel at cross section location #1. View is looking downstream (west).

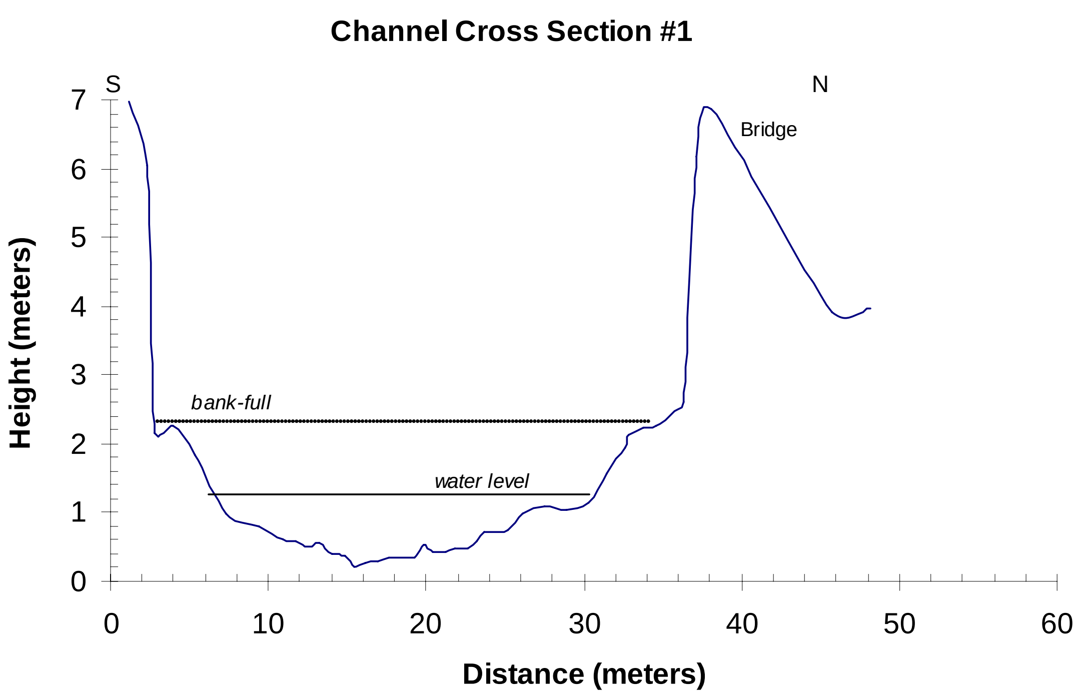


Figure 6. Channel topography at cross section #1.

Channel Description -Cross Section #2

Cross section #2 was located approximately 300 meters upstream from cross section #1. At this site, the banks are composed of Holocene age meandering stream deposits, which include coarse channel gravel overlain by overbank sand and silt. The natural banks are 3 meters above the channel base, and a well developed soil is present in the upper sediments. Land-use on the surrounding floodplain is primarily agricultural land on the north bank, and mixed scrub/forest vegetation on the south bank. Grass and brambles covers much of the channel banks and exposed bar surfaces (Figure 7).

A riffle is formed at this site, due to the construction of a natural transverse channel bar, composed primarily of gravel and cobbles (see Figure 7). The maximum water depth across the riffle was 0.75 meters, and the average mid-channel velocity was 0.16 meters per second. The low-flow channel was 36 meters wide. The stream has developed a wide, shallow channel here (Figure 8), most likely due to the loose nature of sediment comprising the bed and banks.

At low flows, the slope of the water surface varies significantly along the length of the channel (Figure 9). The average slope of the water surface between cross sections #2 and 3 was 2.62%, but over the bar crest the slope was 11.5%, and upstream at the beginning of the bar the slope of the water surface was 1.9%.

Figure 7. Photograph of channel at cross section locations 2 and 3. View is looking upstream (east). Cross section #2 was measured across the riffle in the foreground, and section 3 upstream where person (for scale) is standing in the background.

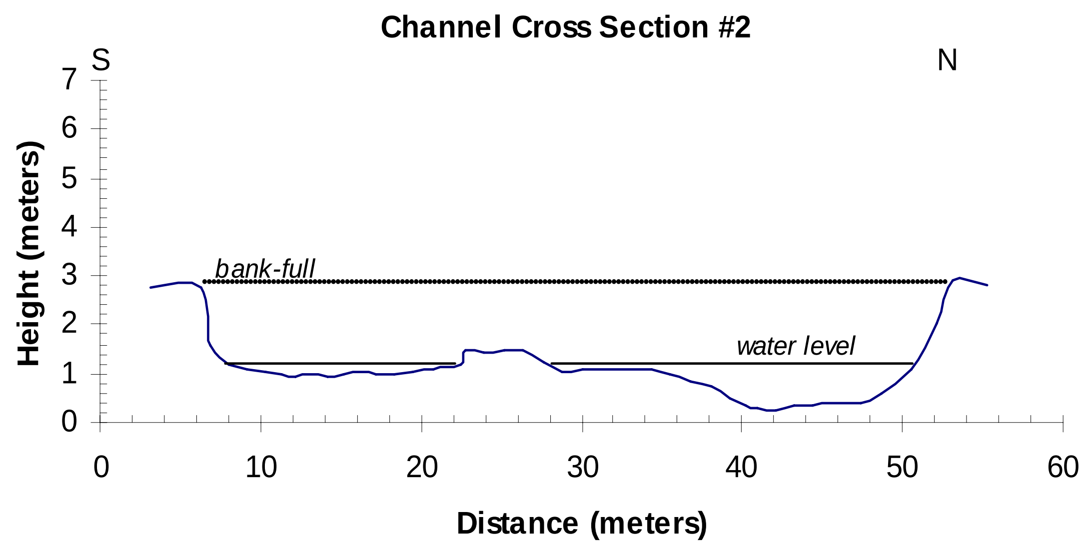


Figure 8. Channel topography at cross section #2.

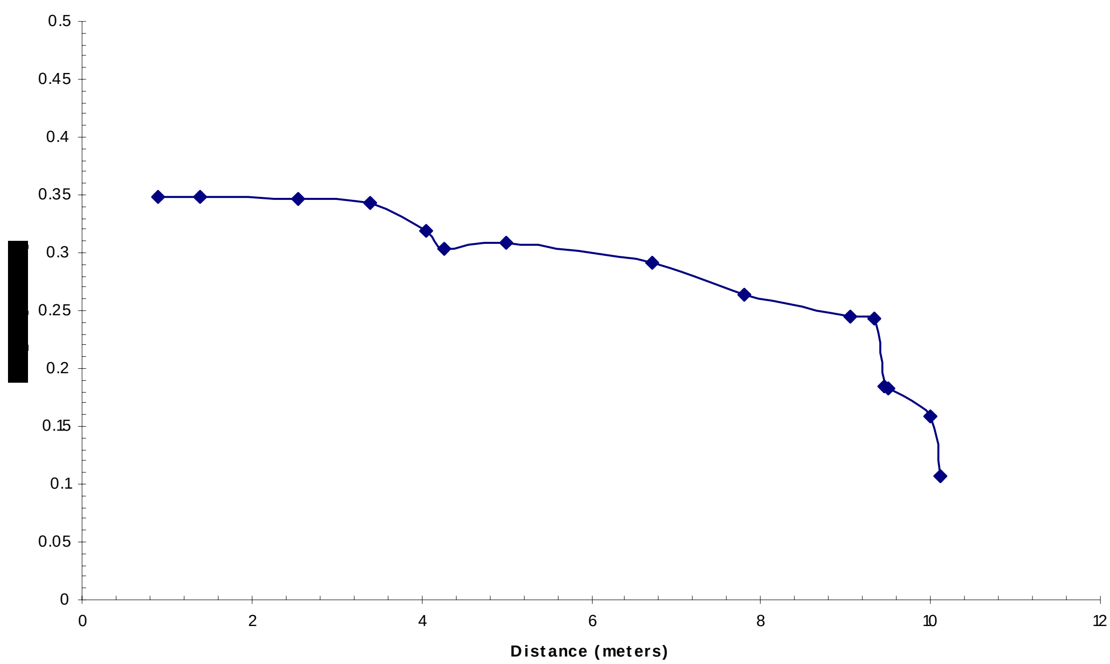


Figure 9. Slope of water surface between cross sections # 2 (downstream) and 3 (upstream). Steepest slope is over the downstream edge of a channel bar.

Channel Description -Cross Section #3

Cross section #3 was located at the beginning of a channel bar (described above, see Figure 7), 10 meters upstream from section #2. At this site, the banks are 2 meters above the channel base, and are composed of Holocene age meandering stream deposits, including coarse channel gravel overlain by overbank sand and silt. Within the bankfull area, smaller sandy terraces have developed, presumably due to sediment accumulation during recent, low-magnitude flood events.

The channel at site #3 is wide and shallow (Figure 10). Exposed and vegetated gravel bars line the sides of the channel (Figure 7). The average mid-channel velocity was 0.31 meters per second, maximum depth 0.2 meters, and channel width at low flow was 27 meters.

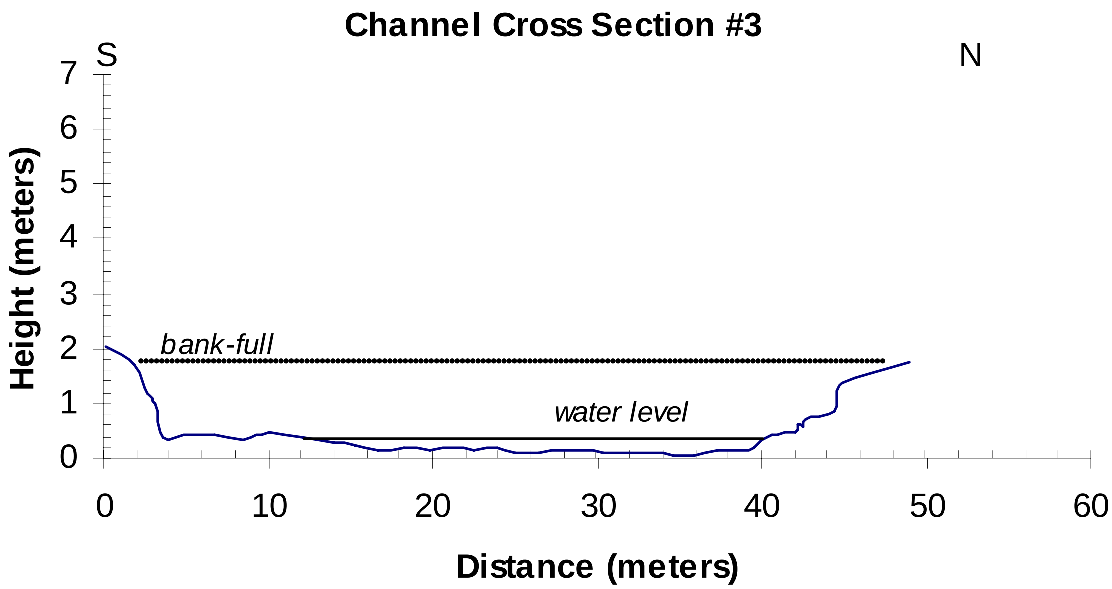


Figure 10 . Channel topography at cross section #2. See Figure 7 for a photograph of this site.

Sedimentology

The nature of sediment in the stream channel plays an important role in stream ecology. Grain size and sorting in the channel are a function of flow dynamics, and the resulting sediment distributions serve as habitat for a variety of aquatic organisms.

The channel substrate was first generally described for clast size, shape, sorting (the range of grain sizes present), and lithology (rock type). At two cross sections, clast sizes were quantified by systematically measuring the diameter of the intermediate axis of gravel clasts exposed along the bed of the channel.

The channel at cross section #1 contains boulders scattered throughout gravel and cobbles, overlying sandstone bedrock, which is exposed in the center of the channel. Most sediments were well rounded, generally poorly sorted, and clast supported with minor amounts of sand and silt between larger clasts. Much of the gravel is composed of quartzose lithologies, derived from reworking of older glacial outwash. The remaining sediments are composed of sandstone and shale derived locally from erosion of Devonian strata. Detailed grain size analyses were not conducted at this stretch, due to the large, predominantly boulder sized material, and bedrock, that made up the channel bed.

The grain size distribution of sediments along the channel bottom at cross sections #2 and 3 (a riffle and run, respectively) were measured by systematically sampling materials lining the channel bottom (675 clasts at cross section #2, and 495 clasts at section #3). Both channel cross sections contained poorly sorted, moderately well rounded gravel and minor amounts of sand and silt (Figure 11). A pebble count across both cross sections yielded an average intermediate diameter gravel size of 40 cm. Gravel lithologies were similar to those described for section #1, above.

Hydrology

River flow regimes are an important aspect of stream ecology (Harris *et al.,* 2000; Wood *et al.,* 2000). Peak stream discharges of French Creek are controlled by the Union City dam, built in 1970. Gauging stations throughout the French Creek watershed permit an examination of pre- and post-dam hydrologic conditions. The longest continuous records of discharge in the French Creek watershed were recorded downstream from the study area, at the confluence of French Creek and the Allegheny River (88 years), and at Utica (69 years) (Table 3). Shorter records are also available, however most either only predate or post-date dam construction.

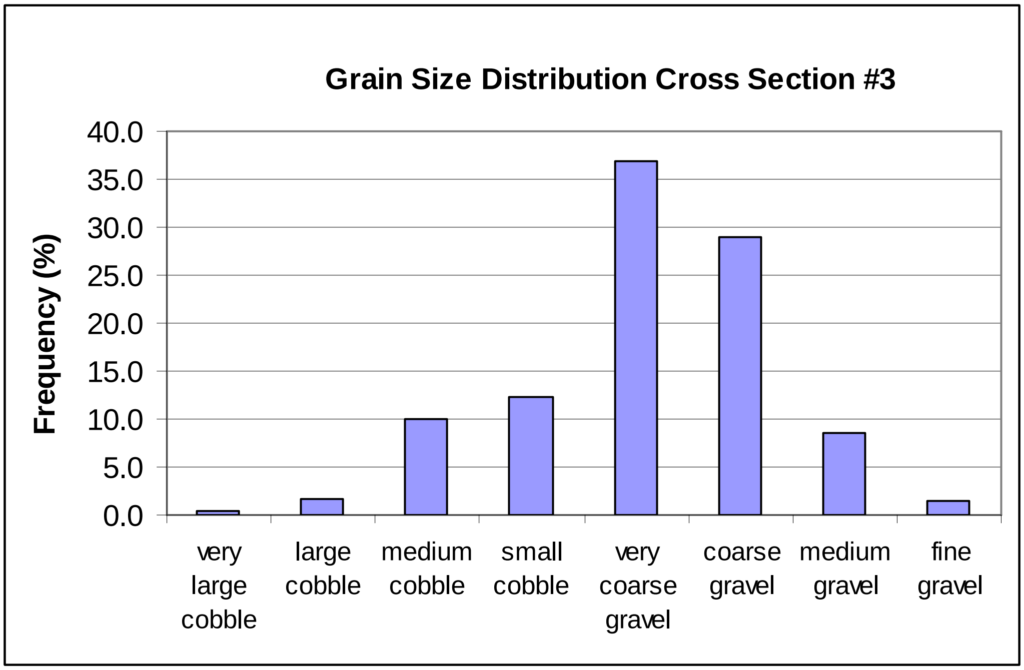
					Discharges		
Location	Years of record	Drainage area	Maximum	Minimum	Average annual peak	Pre-dam average	Post-dam average
		(sq miles)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
Franklin	88	5982	196000	31600	72143	80738	57203
Utica	69	1028	35600	9140	13453	14611	12114
Carelton	17	998	38000	14800	17288	17288	-
Saegertown	19	629	26300	12600	11797	11797	-
Union City	20	221	4430	1250	2468	-	2468
Carters Corners	61	208	20000	2350	7695	7788	-
Wattsburg	27	92	6350	1860	4015	-	4015
Sugar Creek	47	166	10000	2060	5600	not dammed	not dammed

Table 3. Discharge statistics for selected gauging stations along French Creek. Cfs = cubic feet per second.

Analysis of annual series discharge data collected by the U.S.G.S. clearly shows differences in peak discharges through time (Figure 12). Annual series discharges include only the largest discharge for each year of record (Dunne and Leopold, 1978). It is generally accepted that larger peak discharges are most responsible for the greatest morphological adjustment of floodplains, including mobilization and redistribution of sediment, organic matter, and landform creation. Discharges smaller than bankfull capacity, while more frequent than overbank flows, have less potential to alter the riverine landscape, and do nothing to impact the floodplain proper.

Figure 12 clearly shows not only a decrease in average peak discharges, but also decreased peak flow variability from the pre- to post dam period. Total variability in discharge can be expressed by the standard deviation of discharges in each period. (The standard deviation is a measure of how widely values are dispersed from the average value, the mean). The pre-dam standard deviation at Utica was 3961 cfs, where as the post dam standard deviation was 2948 cfs. The difference between these values demonstrates that there has been a 25.6 % decrease in annual series flow variability since dam construction at Union City. Flow variability measured on French Creek at the confluence with the Allegheny River at Franklin has decreased by 54 %.

Decreased flow variability corresponds with fewer, and smaller, overbank flow events. The net result is less interconnectedness between in-channel stream environments and the floodplain setting, which impacts the mobilization of organic matter and nutrients that sustain healthy ecosystems. For example, a large statistical analysis investigating the distribution of fish species as a function of environmental variables indicated that species diversity decreases with decreasing stream flow variability (Koel, 1997). And, recent significant stream management programs recognize that peak flow variability is one of the most important aspects of maintaining a healthy stream ecosystem and restoring habitat diversity (Gosford-Wyong Councils, 2001).



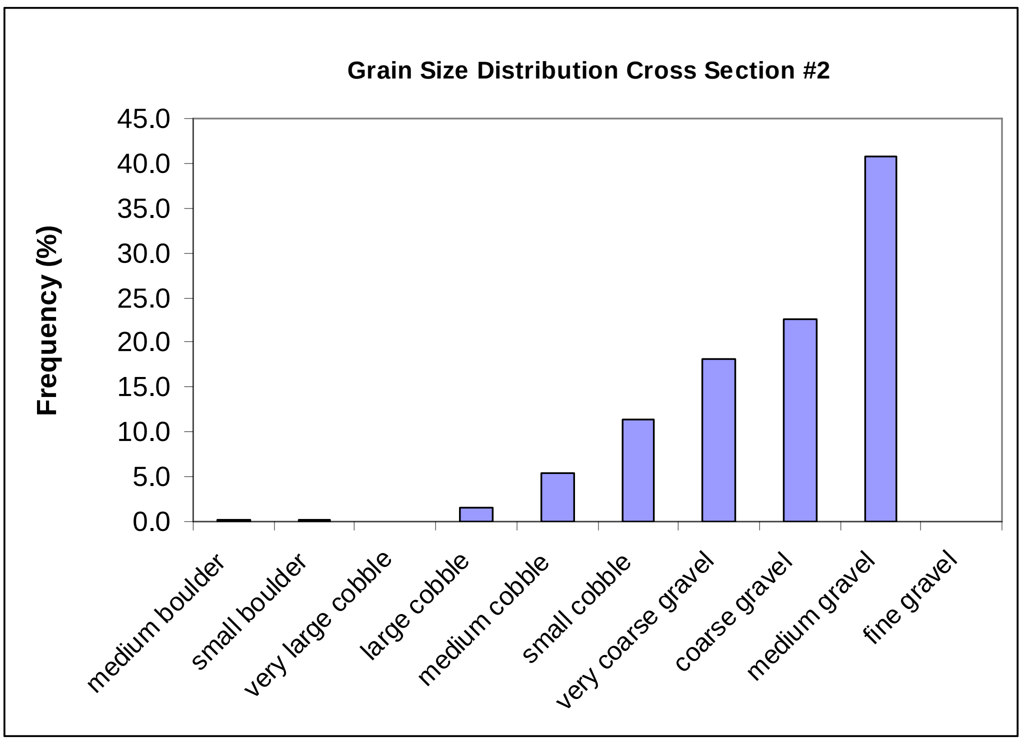
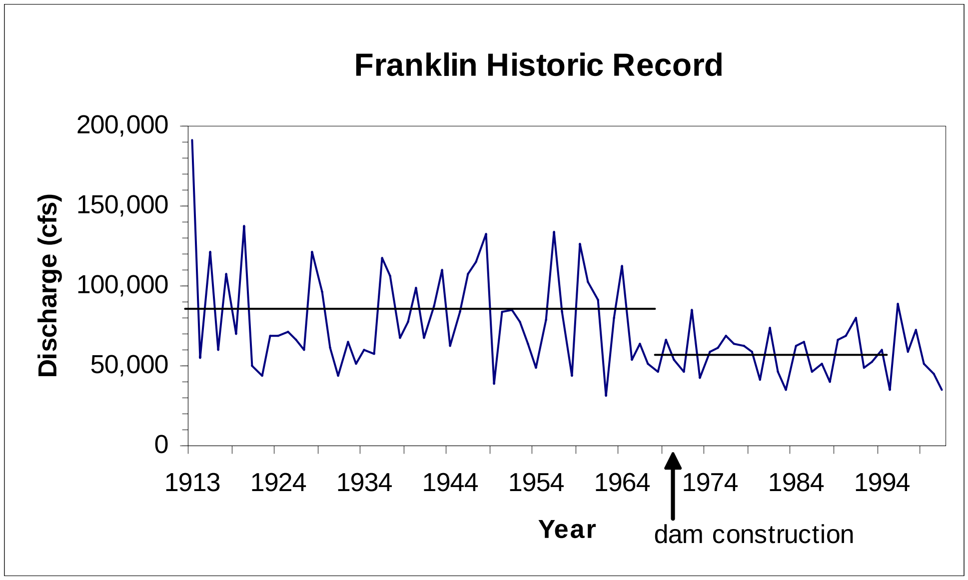


Figure 11. Grain size distribution of clasts exposed along the channel bed. Grains sizes measured from the intermediate axis of clasts.



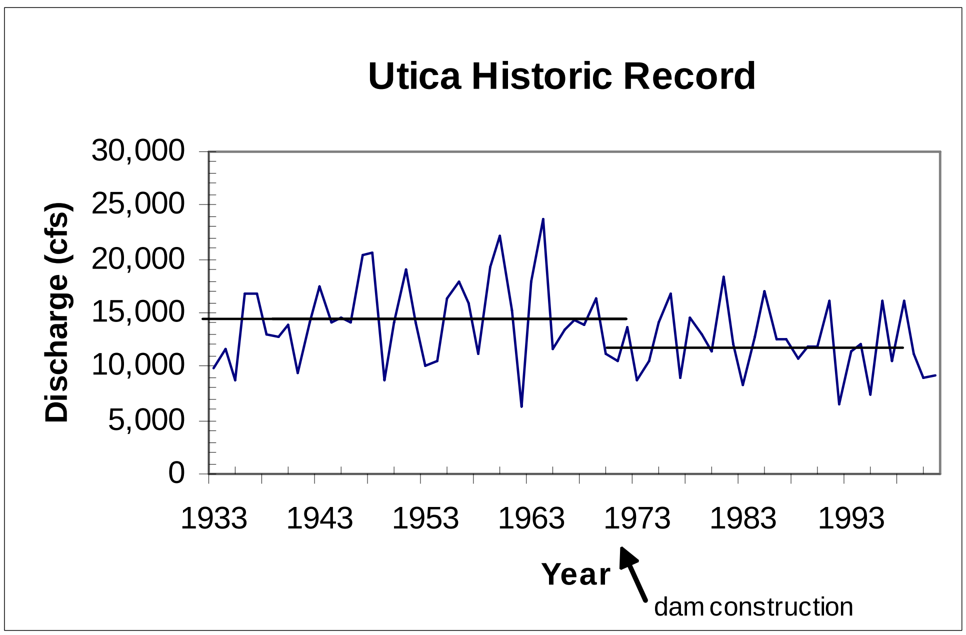


Figure 12. Annual series discharges on French Creek at the confluence with the Allegheny River (A), and at Utica (B). Horizontal lines indicate average annual series discharges for the pre-and post-dam periods.

Summary

This report documents the physical environment of a portion of the French Creek watershed, including the geomorphology, sedimentology, and hydrology of the channel. Basic physical parameters of the stream system are documented in order to provide base-line data that may be used as a reference for future stream monitoring efforts.

The study site includes a natural run and riffle sequence and a disturbed section south of the Union City dam, chosen to best represent stream environments typical of French Creek. Physical parameters documented here include: channel cross sectional area and shape, flow velocity and discharge at low flow, bedrock geology, river bed substrate (grain size and sorting), bank stability and riparian zone descriptions. Changes in these parameters through time can be documented and compared with changes in land-use and other environmental controls, in order to better understand how these variables affect local stream ecology.

Based on the limited observations described above, stream morphology does not appear to have changed radically over the last several hundred years or so, with a few exceptions. For example, French Creek had been an actively meandering stream in the past, as indicated by the occurrence of many abandoned channels (visible in aerial photographs, and recorded in the sedimentary record) that are most likely late Holocene in age. However, localized revetments have restricted channel migration, resulting in channel scouring and deepening. Coarse grained sediments scoured from those locations are deposited downstream as channel bars, which fill the channel and force floodwaters to further scour banks opposing those revetments.

This report also incorporates a study of flow variability, which is an important aspect in the health of natural stream ecosystems. Natural peak flow variability has decreased since the construction of the dam at Union City, however the impact of that change in flow regime on local species diversity is not known. In many other watersheds, a decline in flow variability is tied to decreased stream biodiversity, as the linkages between floodplain and channel are reduced through peak flow reduction. A reduction in overbank floods and the fine-grained sedimentation that accompanies those events requires that that fine material must still be in the channel. Increased fine grained material in the channel decreases habitat for aquatic insects and some fish. Future impacts on flow variability through the proposed alteration of the Union City dam will likely reduce peak flow variability even further. The result, based on comparisons of other streams, will be reduced biodiversity.

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