The Effects of Riparian Health on Stream Health

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Abstract

Riparian zones are areas of vegetation located between surrounding terrestrial and aquatic ecosystems. They reduce the magnitude of runoff and other forms of degradation from agricultural and urban areas from entering the stream to increase stream health. This study looked at a set of three macroinvertebrate families, Ephemeroptera, Plecoptera, and Tricoptera, to evaluate the health of second order streams in Northwest Pennsylvania. In order to determine riparian health two assessment check-lists were used: a Riparian, Channel, and Environmental Inventory Analysis, and a Water Quality Network and Habitat Assessment. The results of this study on the French Creek Watershed demonstrated that riparian health plays an important role on the health of a stream

Introduction

Many towns and cities in the United States were developed along the banks of streams and rivers. Streams and rivers have been used to transport goods since the Europeans began to settle in the U.S, starting in the early 1670's (Delong, 2005). Agricultural land is often also placed next to rivers due to easy access to water for irrigation and transportation of goods for sale. Stream health can be severely altered by these activities (Karr, 1991). When the vegetation immediately bordering streams is cut down or destroyed sediment cannot be slowed enough to prevent it from entering the stream directly or nutrient loading (Burt, 1999). In many areas, the natural water flow of streams has been redirected for human consumption. Postel and colleagues (1996) point out that over half of streams in the world are currently diverted for human use (farming, drinking, transportation) and this is likely to increase over time.

Riparian buffer zones are strips of vegetation along streams, rivers, or lakes that act as a boundary between terrestrial and aquatic ecosystems (Allan and Castillo, 2007, Gregory, 1991). Riparian zones ideally are 5-15 meters wide paralleling a stream on both sides (Naiman, 1993). They are essential in order to maintain healthy interactions between terrestrial and aquatic ecosystems by protecting the stream from pollution, sediment loading, erosion, and providing shade to cool water temperatures (Goldstein, 1994, Gregory,1991).

Historically, riparian zones surrounded streams throughout North America, but with the spread of agriculture they have become sparse (Hurt, 2002). In areas where they are present, riparian zones act as a sink for excess nutrients. Riparian zones are effective in reducing sediment runoff, large grasses and leaf litter stops large sediment that is present in high flow conditions (Lowrance, 1984). Grass in riparian zones decreases the velocity of the runoff which allows for sediment to settle and disperse into the riparian zone (Burt, 1999).

Fertilizer has been readily available since the 20th century, which allowed humans to significantly alter the global nitrogen cycle over the past half-century (Galloway and Cowling, 2002). The excess nitrogen is taken with surface flow and transported from streams to larger bodies of water where it accumulates and alters ecological processes (Rabalais, 2002). One alteration caused by this is an algal bloom, a form of eutrophication where a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life. This often

results in the reduction of dissolved oxygen in the system, which causes hypoxia, leading to extensive killing of both invertebrates and fish species in the aquatic ecosystem. This is most commonly known as a "dead zone" (Camargo and Alonso, 2006). In the Gulf of Mexico, between 1993 and 1999, the hypoxia zone increased from 13,000 to 20,000 km^2 from the discharge of the Mississippi River. This resulted in the deaths of numerous species (Mitsch, 2006). Peterjohn and Correll (1984) report a significant difference in the amount of nitrogen retention between riparian forests (89% retention) and cropland (8% retention) in the Rhode River watershed located on the western shore of the Chesapeake Bay. Likewise Likens (2010) wrote that in some areas in the northeastern U.S. over 50% of nitrogen inputs were taken up by riparian buffers in more recent studies. Another study done in several countries of Europe showed that annual nitrogen removal rates by vegetation in riparian buffers were much lower, 20-30% in eight sites (Sabater, 2003)

Biomonitoring is the process of assessing the condition of a stream by sampling the organisms that are present (Karr and Chu, 1999). To assess the health of the stream a Water Quality Network Assessment (WQNHA) can be performed (Appendix C). This assessment is taken from the Pennsylvania Department of Environmental Protection Bureau of Water Standards and Facility Regulations (PA DEP, 2012). The parameters that are assessed over a 100 m stream section are: in stream cover, epifaunal substrate, embeddedness, velocity/depth regime, channel alteration, sediment deposition, frequency of riffles, channel flow status, condition of banks, bank vegetative protection, grazing or other disruptive pressure, and riparian vegetative zone width. Each parameter is ranked from 1-5(poor) 6-10(marginal) 11-15 (suboptimal) and 16-20 (optimal).

Another assessment form is a Riparian, Channel, and Environmental Inventory (RCE). The inventory was adapted by Peterson as a quick way to view landscapes where non-point source pollution and agriculture dominate, and the environmental condition of small streams can be assessed and allowed the evaluation of the physical condition of the riparian zone and stream channel (Peterson, 1992). It contains twelve characteristics that depict the structure of the riparian zone and stream channel morphology within a 100 m section of the stream. This measurement may be problematic because stream health is a product of the whole watershed, not just a 100 m section.

Bioindicators, or ecological indicators, include biological processes, species, or communities that are used to assess the quality of the environment and how it changes over time (Holt and Miller, 2011). Changes in the environment are often attributed to human activities or natural stressors (e.g., drought, late spring freeze), although human stressors form the primary focus of bioindicator research (Miller, 2011, Straffen, 2003). Macroinvertebrates are preferred as bioindicators because they exhibit five traits explained by Miller (2011): 1) They have a relatively long lifespan, 2) Their natural history is relatively well known, 3) They are found universally in perennial stream systems, 4) They can be identified easily and cheaply, and 5) They are affected by physical, chemical and biological changes in the stream. Additionally, macroinvertebrates are numerous and easy to collect (Neumann, 2003, Hooda, 2000, Straffen, 2003).

Streams are ranked by size or order, which was first developed by Columbia University Geosciences professor Arthur Strahler in 1952 (Ward and D'Ambroso, 2008) which ranks the streams by amount of discharge in categories of the 1^{st} – 12^{th} order. Strahler had modified an earlier model into the one shown in Figure 1; the first permanent stream is ranked as 1^{st} order. As two 1^{st} order streams meet they become a 2^{nd} order stream but two 2^{nd} order streams have to meet to compose a 3^{rd} order stream (Allan and Castillo, 2007). The Mississippi River is the largest river in the United States, 10^{th} order stream, while French Creek is considered a 5^{th} order stream (Delong, 2005).

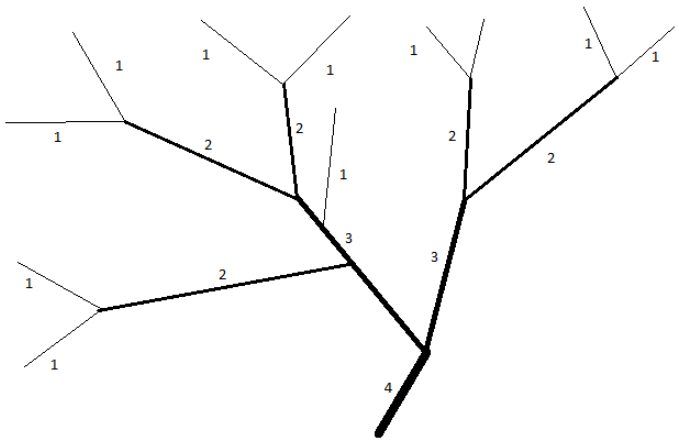


Figure 1: Diagram of how stream systems are ordered

The French Creek watershed covers roughly 3,250 square kilometers of Crawford County in Northwest Pennsylvania (Helmreich, n.d.). The creek flows into the Allegheny River, the Ohio River, and eventually the Mississippi River. French Creek is known as one of the most ecologically diverse streams in Pennsylvania with over 80 fish species and 29 native mussel species (Smith and Crabtree, 2010). This is likely due to the fact that many of the headwaters have not experienced the stress of high industrial use or acidification because a majority of heavy industry during the early to mid-1900's was downstream of the French Creek Watershed (Smith and Shafer, 2011). Being important to diversity, the conservation plans that are being proposed for the protection of the French Creek Watershed mainly focus on prevention and restoration.

Although the French Creek Watershed is one of the most diverse aquatic ecosystems in Pennsylvania previous research on the area is scarce. Preceding studies of French Creek have looked to reestablish the native Brook Trout species and management and conservation plans that had been proposed (Weisberg 2011, Western Pennsylvania Conservancy 2002). The objective of this study is to evaluate interactions between riparian zones and stream health in the French Creek watershed near Meadville, Pennsylvania. This study is unique in that it compares riparian areas of varying health throughout a diverse and species rich watershed.

Methods

Field Sites

Four 2nd order streams located in the French Creek Watershed in Crawford County, Pennsylvania were selected for this study. The streams include Fossil Creek, Rundelltown Run, Watson Run, and Wolf Run (See Appendix A). Each stream had two sites, one high quality site and one low quality site. Site rankings were determined using assessment tools. The Riparian, Channel, and Environmental Inventory (RCE) grades streams on a scale of 30 (best) to 1 (worst). The two main parameters are land use at the local scale and channel structure of the stream. Within these two parameters there are twelve subcategories (see Appendix C for details). The subcategories were summed together to get the total score of the stream. The other form of assessment was a Water Quality Network Habitat Assessment (WQNHA) issued by the Pennsylvania Department of Environmental Protection Bureau of Water Standards and Facility Regulations habitat assessment form (Appendix D). Like the habitat assessment form, parameters were scored, 1-5(poor) 6-10(marginal) 11-15 (suboptimal) and 16-20 (optimal), and

summed to assess the health of the stream and riparian area. The scores are then calculated for a 100 m stream reach and a total score is given to the stream. Temperature, pH, and total dissolved solids were recorded before every visit to make sure none of the chosen factors would account for low invertebrate counts.

Collection of Invertebrates

Sampling was conducted once every three weeks for a total of 3 samples with each sample taking 6 days to complete a trial (October 20-October 26, November 10 – November 16, December 1- December 7). Four streams were sampled with two 100 m selected stretches in each stream. Kicknets were used to collected macroinvertebrates in 3 riffles, 3 runs, and 3 pools for each 100 m stretch. Each kick was twenty seconds, totaling nine kicks per stretch. Specimens were strained using a sieve to remove larger leaves and pebbles which were returned to the stream. Each kick was placed in separate container preserving differences between riffles, runs, pools, and trials. The specimens and remaining sediment and detritus were placed into containers with 70% ethanol to preserve macroinvertebrates.

Identification of Invertebrates

Identification of the specimens was performed under a microscope in the lab. Macroinvertebrates were separated by family using identifying keys in Peckarsky (1990). Additionally, Dr. Bradshaw-Wilson assisted in the identification of a portion of the macroinvertebrates. The three target macroinvertebrate families found were Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies).

Data Analysis

The abundance of each order of macroinvertebrate as well as the diversity of the families was calculated for each stretch. Abundance of individuals was found by adding each indiviual within an order. To find the mean diversity per stream, each family was summed and averaged between trials. Data was analyzed using an ANOVA with independent variables being the stretches, areas, streams, and trials. Statistical significance was found between variables ($\alpha = 0.05$). The dependent variables were the abundance and diversity of the three orders of macroinvertebrates. A Tukey test was performed to determine means separation for each test.

Results

Habitat evaluation

Field assessment scores were based on visual assessment of the stream and surrounding vegetation composition. The criteria of the RCE and WQNHA that were observed above can be found in appendix B. Using both the RCE and the WQNHA, to ensure the accuracy of stretch scores, Stretch 1 was the lower scored riparian area and Stretch 2 was the higher scored or a healthier riparian area (Table 1). The RCE and WQHNA did not show vast differences between scores of Stretch 1 and Stretch 2. The riparian scores for the WQNHA and RCE both varied more for Stretch 1. The difference between Stretch 1 and Stretch 2 showed that both assessment tools found a damaged and healthy riparian zone in each stream.

Table 1: Riparian Channel and Environmental inventory and Water Quality Network Habitat Assessment totals

	RCE Score			**WQNHA Score**		
Stream	**Riparian**	**Channel**	**Total**	**Riparian**	**Channel**	**Total**
Fossil						
Stretch 1	35	110	145	37	117	154
Stretch 2	95	125	220	64	132	196
Rundell						
Stretch 1	40	110	150	40	110	150
Stretch 2	105	155	260	70	138	208
Watson						
Stretch 1	55	110	165	46	102	148
Stretch 2	105	125	230	72	141	213
Wolf						
Stretch 1	40	101	141	33	119	152
Stretch 2	95	125	225	68	139	207

Water Chemistry

Temperature gradually decreased as the experiment progressed, Trial 1 showed the highest temperatures while Trial 3 showed the lowest. The water's pH stayed within a range of

8.3 ± 0.3 throughout sampling. Levels of total dissolved solids (TDS) did not change over time within any of the streams, but it was consistently higher at Watson Run (Table 2).

Table 2: Baseline chemistry measurements for each stream

Trial Number	Temperature (^{o}C)	pH	Total Dissolved Solids
Fossil			
1	6.4	8.5	60
2	5.5	8.3	60
3	3.0	8.3	60
Rundell			
1	5.7	8.1	60
2	3.4	8.6	60
3	1.5	8.4	60
Watson			
1	8.0	8.2	70
2	6.2	8.2	70
3	2.3	8.1	70
Wolf			
1	9.3	8.1	60
2	5.0	8	60
3	1.7	8.1	60

Abundance

Ephemeroptera and Tricoptera were the most abundant in both stretches while Plecoptera was the least abundant (Figure 2). Data shows that all three orders show significant differences across the three criteria: stream, area, and stretch.

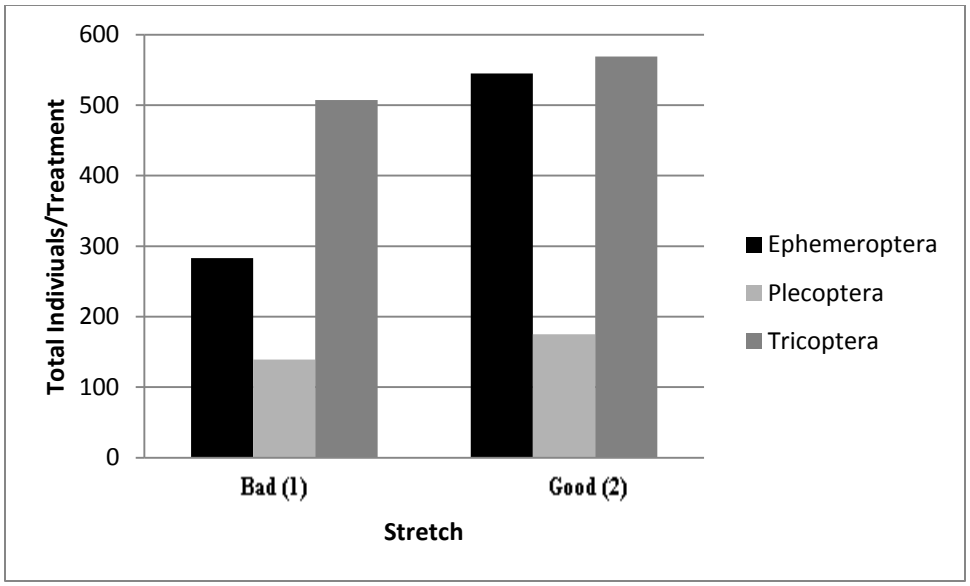


Figure 2: The abundance of the three target orders between Stretch 1 (poor) and Stretch 2 (healthy). Tricoptera were abundant in both stretches while Ephemeroptera showed significant differences between stretches

First, the abundance of Ephemeroptera varied significantly between streams ($p = 0.0021$, $df = 3$, $F = 5.494$), areas ($p = < 0.0001$, $df = 2$, $F = 16.573$), stretch ($p < 0.0001$, $df = 1$, $F = 60.355$) and Stretch x area ($p = 0.0110$, $df = 2$, $F = 4.860$). A Tukey HSD test demonstrated that the abundance of Ephemeroptera in Watson Run was significantly greater than Fossil and Rundell (Figure 3).

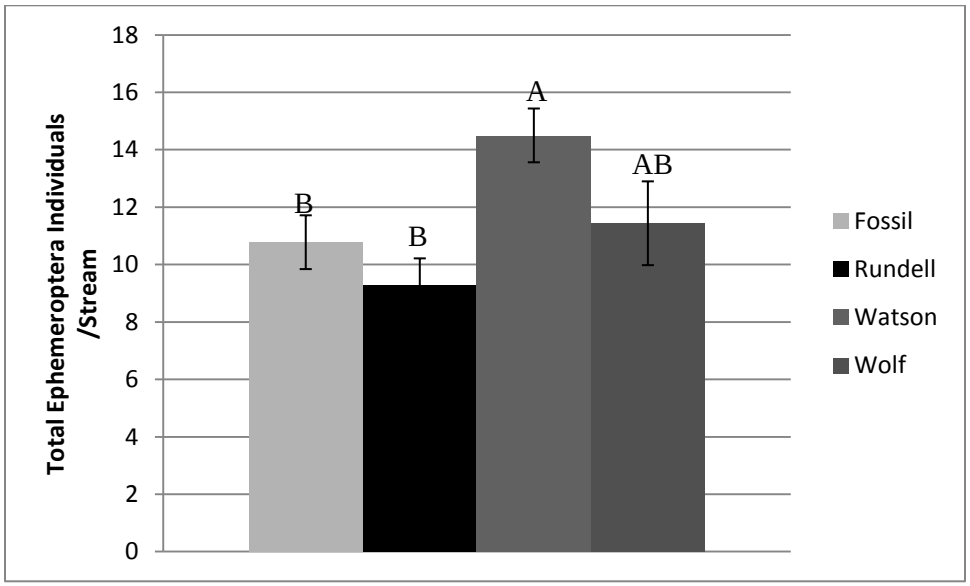


Figure 3: The mean abundance of Ephemeroptera per stream for Fossil, Rundell, and Watson and Wolf streams. Significance was found between Watson and both Fossil and Rundell.

Riffles and runs were significantly greater than pools (Figure 4). Stretch by area had statistical differences between riffle and runs in Stretch 2 and pools in Stretch 2 as well as riffles, runs and pools in Stretch 1 (Figure 5).

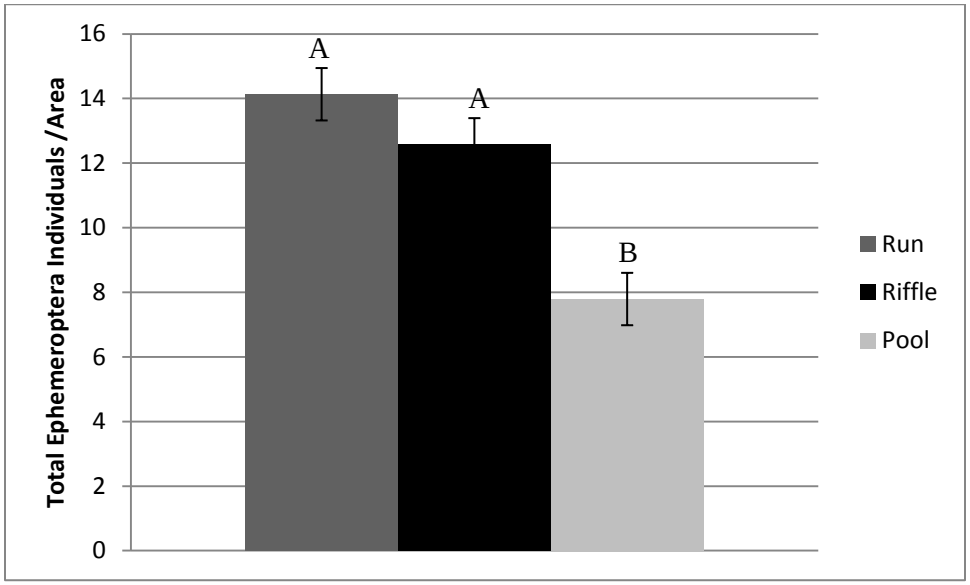


Figure 4: The mean abundance of Ephemeroptera per riffle, run, and pool. Runs had significantly higher totals of Ephemeroptera individuals than pools

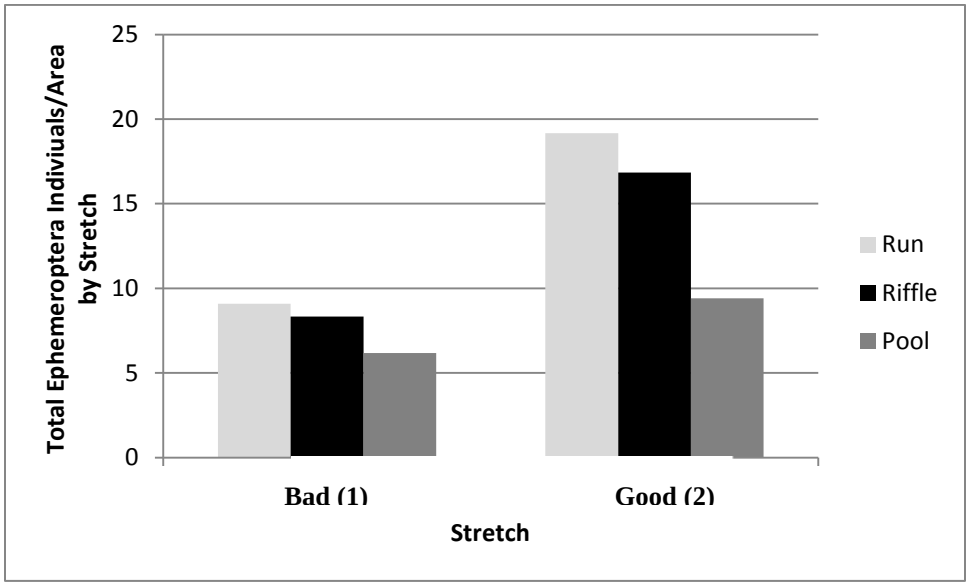


Figure 5: The mean abundance of Ephemeroptera per riffle, run, and pool by stretch. Stretch 1 showed significantly higher Ephemeroptera individuals than Stretch 2

Next, the abundance of Plecoptera only showed statistical differences between streams ($p = 0.0159$, $df = 3$, $F = 3.725$), all other variables showed no significance. Wolf and Rundell were the two streams to show significant differences, the other two streams (Fossil and Watson) showed no significance (Figure 6). An ANOVA test on the abundance of Tricoptera showed no significance between any of the variables above.

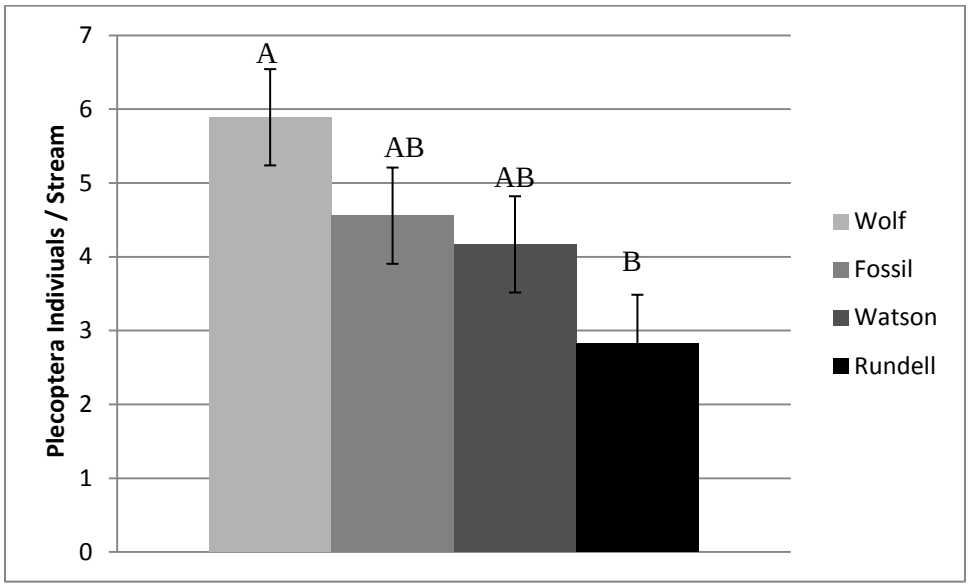


Figure 6: The mean abundance of Plecoptera per stream. Significance was found between Wolf and Rundell runs

Variation in total abundance between areas ($p = 0.0006$, $df = 2$, $F = 8.336$) and stretches ($p = < 0.0001$, $df = 1$, $F = 25.607$) was statistically significant. Abundance did not vary by streams and stretch by area were not statistically different. A Tukey HSD test showed that riffles and runs were statistically different than pools.

The mean number of individuals belonging to each family within Stretch 1 and 2 is available in Table 3. The most commonly found families in each stretch were Heptageniidae (Ephemeroptera) and Hydropsychidae (Tricoptera). The order Plecoptera was the least abundant as a whole of the three bioindicators. Overall, Stretch 2 averaged more individuals that Stretch 1, with the three families (Palingeniidae (Ephemeroptera), Peronacyudae (Plecoptera), and Psychomyiidae (Tricoptera)). The biggest difference in mean individuals between stretches is in the family Heptageniidae where there is an average difference of 5 individuals per stream.

Table 3: Mean number of each family collected for each stretch

	Stretch 1	Stretch 2
Ephemeroptera		
Heptageniidae	5.08 ± 1.37	10.33 ± 3.01
Leptophlebiidae	2.11 ±0.67	2.66 ± 0.62
Ephemeridae	2.23 ±0.58	2.28 ± 0.53
Palingeniidae	2.60 ± 0.73	2.16 ±0.65
Oligoneuriidae	1.13 ± 0.20	1.65 ± 0.45
Potamanthidae	1.70 ± 0.39	2.73 ± 0.69
Plecoptera		
Nemouridae	2.19 ± 0.92	2.30 ±0.73
Taeniopterygiadae	2.42 ± 0.67	2.65 ± 0.66
Pteronarcyidae	2.47 ± 0.82	2.81 ± 0.95
Peronacyudae	2.43 ± 0.81	2.00 ± 0.49
Tricoptera		
Hydropsychidae	9.42 ± 2.62	10.22 ±3.49
Glossosomatidae	2.18 ± 0.62	2.50 ± 0.67
Psychomyiidae	2.79 ± 1.15	2.33 ± 0.80
Phryganeidae	3.50 ± 1.09	3.79 ± 2.12
Polycentropodidae	2.00 ± 0.96	2.94 ± 0.78

Diversity

An ANOVA was used to analyze diversity of the three orders to determine statistical significance with respect to family diversity. Ephemeroptera family diversity (Figure 7) shows that there is a significant difference between stretch ($p = 0.0004$, $df = 1$, $F = 13.802$) and areas ($p = 0.0027$, $df = 2$, $F = 6.548$). Stretch 1 had significantly greater Ephemeroptera diversity than Stretch 2. Runs and pools had significantly greater diversity of families through a Tukey's HSD.

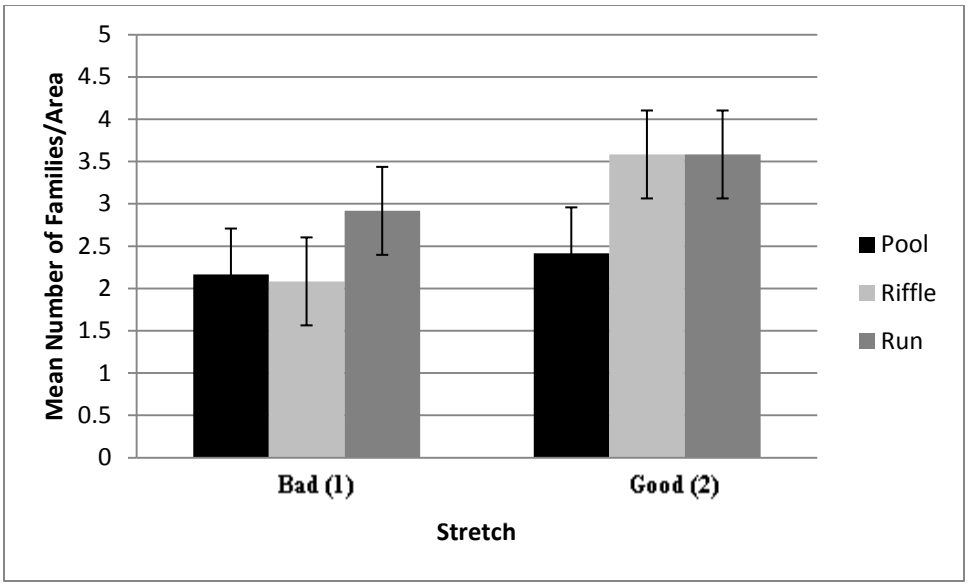


Figure 7: Mean diversity of Ephemeroptera families per area

Plecoptera family diversity varied significantly between stretches ($p = 0.0006$, $df = 1$, $F = 13.260$) and areas ($p = 0.0018$, $df = 2$, $F = 7.0501$) (Figure 8). Using a Tukey's HSD, significant differences between runs and pools were found.

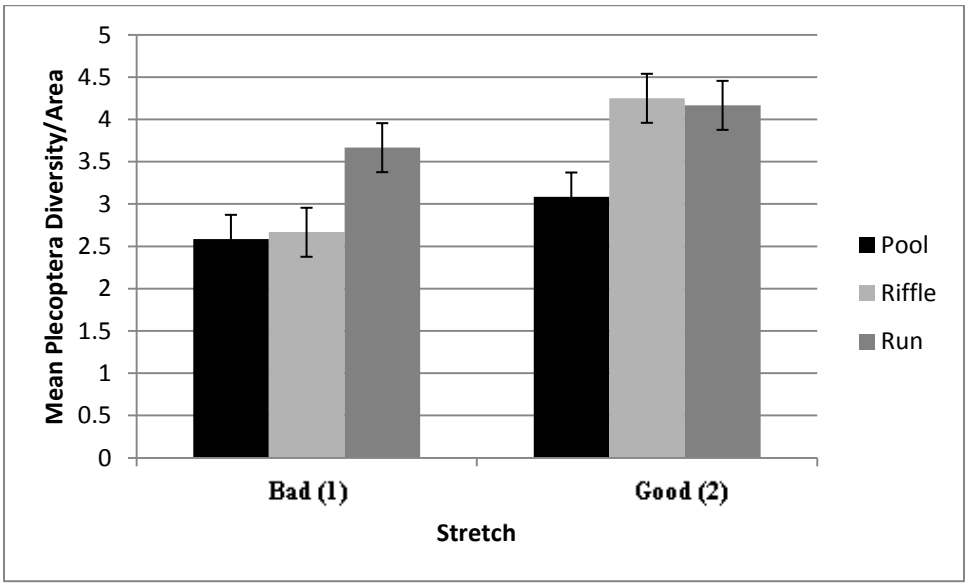


Figure 8: Mean Plecoptera family diversity by area per stretch. Runs and pools showed significant differences.

Tricoptera data shows that there is significance between stretches ($p = < 0.0001$, $df = 1$, $F = 18.343$), areas ($p = 0.0250$, $df = 2$, $F = 3.920$), and streams ($p = 0.0437$, $df = 3$, $F = 2.868$).

With the use of a Tukey's HSD test, runs were statistically different than pools (Figure 9). Fossil Creek and Rundelltown Run both showed significant differences (Figure 10).

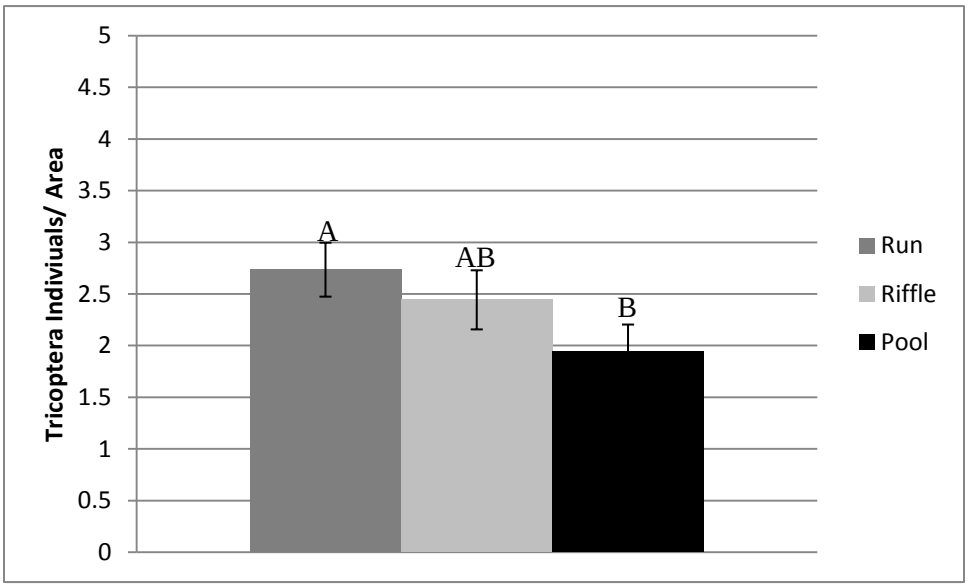


Figure 9: Mean total family diversity per riffle, run, and pool.

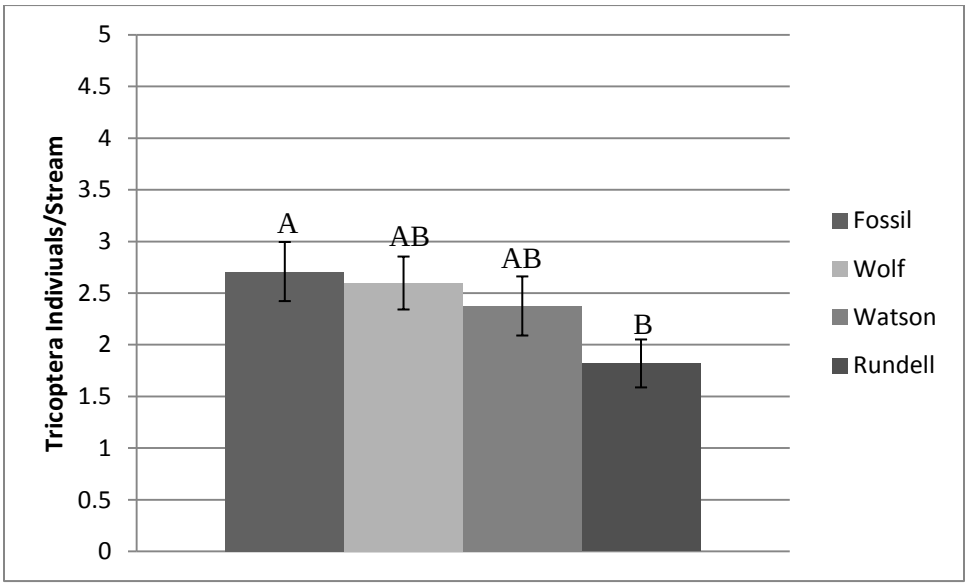


Figure 10: Mean Tricoptera diversity per stream, Fossil and Rundell were significantly different

Total family diversity (Figure 11) was significantly greater for Stretch 2 than Stretch 1($p = 0.0013$, $df = 1$, $F = 11.320$). The difference between Stretch 1 (3.22 ± 0.246) and Stretch 2 (4.11 ± 0.227) was 0.89 families per stretch. Total diversity among areas (Figure 12) showed that

riffles and runs both had the highest levels of diversity; however, this was not significant ($p = 0.1325$, $df = 2$, $F = 2.089$).

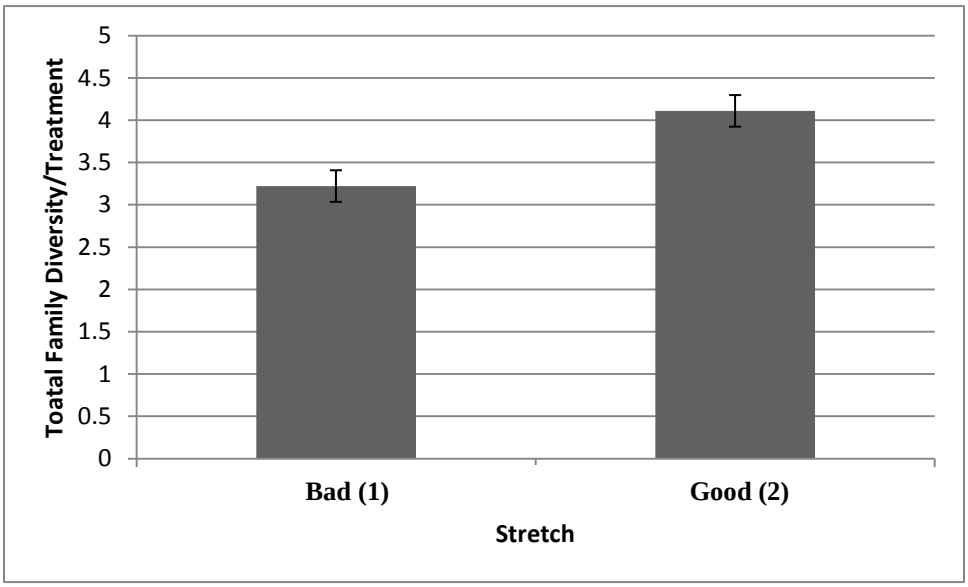


Figure 11: Depicts the mean total family diversity per stretch. Stretch 2 (healthy) had a significantly higher mean (3.85 ± 0.160) than Stretch 1 (poor) (2.97 ± 0.147).

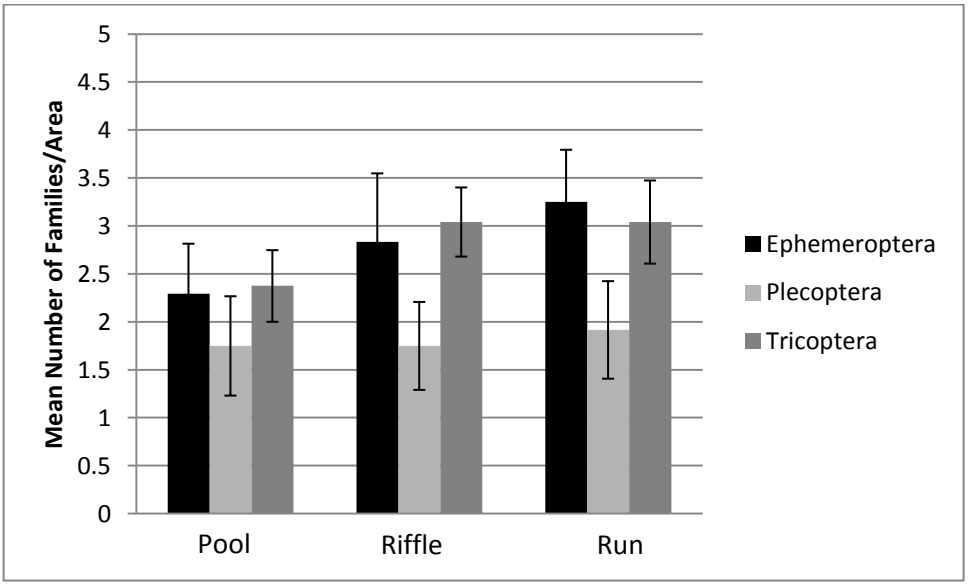


Figure 12: Mean number of families per area in each location. Riffles and runs had the highest mean of families for Ephemeroptera and Tricoptera, Plecoptera did not show significant differences

Discussion

The main results found in this study were that as the health of a surrounding riparian zone improves, the health and biological quality of that stream improves as well. Throughout the data presented about the French Creek Watershed, it is clear that as riparian health increases the average number of macroinvertebrates also increases. The main problem that has arisen is that as human populations grow, room is needed to expand and live (Karr, 1991). This is what can lead to the decline or even the removal of healthy riparian zones to build structure or roads, which in turn can cause the channelization or reduction of habitat diversity, decreasing species richness (Mancini et. al., 2005, Teels et. al., 2006).

Agricultural land use degrades streams by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitat, and altering flows (Allen, 2004). Runoff, such as manure, fertilizer, and pesticides from agricultural areas, which enters streams, has a high concentration of nitrogen (Rabalais et al., 2002). Many nutrients are located in agricultural areas, and the process and efficiency of filtering and removing these nutrients depends on the vegetation type in the area (Naiman and Decamps, 1997). Streams in forested riparian zones are not only protected because of the removal of excess nutrients through uptake by the vegetation but they buffer streams by protecting them against erosion and improving water quality by retaining sediments from runoff (Peterjohn and Correll, 1984). The roots from trees increase bank stability, so when floods occur, sediment is not washed away (Allan, 2004). When streams are bordered by areas such as cropland and urban areas, it is difficult for stream banks to remain in place when flooded conditions arise (Goldstien et al., 1994). Therefore, a stream bank that is covered in vegetation not only reduces pollution in streams, but also protects against degradation. The healthier Stretch (2) all had higher scores in both RCE and WQHNA for bank and surrounding riparian health over the damaged Stretch (1) showing that sediment and nutrients from runoff can be taken up by the surrounding riparian area.

In this study, other than just using assessment tools a visual assessment was used to determine other problems that might have affected macroinvertebrate levels. For instance in Rundelltown Stretch 1 there was an area where it looked as if a shed had been pushed over the embankment with all of the contents still in it. In Watson Stretch 1 tires were present along the bank as well as areas where cattle were able to enter the stream, this area showed lower diversity

than other areas of the same RCE and WQHNA scores. On the other extreme Watson Stretch 2 had very large, diverse riparian areas where the stream was free to flow in any direction.

Many studies have looked at this interaction and the affects of restoring or removing the riparian zone from around the stream (Lowrance et al., 1984, Mitsch et al., 2001). Teels and colleagues (2006) looked at the health of fish assemblages but found that as riparian areas increased so did stream canopy cover, decreased nutrients entering the stream through runoff and sedimentation in the stream. If canopy cover is low stream temperature may rise above levels to support macroinvertebrates. Also a canopy over the stream can provide organic matter and bank stability for the channel (Roth et al., 1996). These factors were taken into account with the RCE and WQNHA to determine how healthy the overall system was. In each streams sampled, the areas with higher riparian scores also had higher channel scores showing a relationship between the two, however, upstream factors can also affect channel score in areas with good riparian zones.

Also, chemistry data showed other factors, for instance pH, were not affecting the macroinvertebrates that were in the stream, optimum pH ranges for Ephemeroptera, Plecoptera, and Tricoptera is between 6.5-9.5 (Tripole et al., 2008). Temperature decreased at a fast rate during the study because winter had begun to set in and streams had begun to freeze over. This did not affect the amount of specimens collected because no significance was found between trials for any of the target orders

Evaluation of abundance and diversity of sensitive families such as Ephemeroptera, Plecoptera and Trichoptera were used determine stream health. If degradation of riparian zones was present more tolerant taxa would take over the stream (Groffman, 2003). The majority of the specimens that were collected were from the orders Ephemeroptera and Tricoptera. There was one problem with finding high abundances of Ephemeroptera, Plecoptera, and Tricoptera because a large percent was Hydropsychidae (Tricoptera), an indicator that is more tolerant to polluted streams (Jehamalar, 2010). Heptageniidae (Ephemeroptera) was also abundant in this study and is considered to be more sensitive to pollution than Hydropsychidae (Hooda, 2000). In the study by Hooda and colleagues (2000), it was found that as pollution from the dairy farm runoff increased, macroinvertebrate communities suffered. The pollution from the three dairy farms was mostly ammonium and phosphorus and did not pass through a vegetative area before

entering the stream. Schueler (1995) concluded that in general, healthy riparian buffers have the capability to remove up to 75% of sediment, 40% of nitrogen and 50% of phosphorus in both runoff and subsurface flows. This can pair with the results of this study where the healthier riparian area also showed the healthiest stream segments.

Riffles and pools showed significant differences in diversity, this was expected however because riffles usually have higher levels of dissolved oxygen as well as numerous places for Ephemeroptera, Plecoptera, and Tricoptera to seek refuge from predators. In a study of the River Elan and River Wye in Wales, it was found that the majority of their Ephemeroptera, Plecoptera, and Tricoptera were found in riffle areas (52%) and pools were dominated by tolerant chironmids (71%) (Scullion, 2006). Additionally, studies on streams in both North American and the United Kingdom confirmed the conclusions of this study between riffles and pools: There were higher abundances and densities in the riffle areas compared to pools (Gregory, 2005, Logan and Booker, 1983). These studies also concluded that when looking at the differences in riffles and pools, Ephemeroptera showed the largest gaps between the two areas.

Future directions this project could go would be to use Geographic Information Systems (GIS) to pinpoint areas with high rated riparian areas upstream of a location and sample in those areas and do the same with damaged stretches. GIS could refine the process of determining what a higher and lower rated riparian area is eliminating human error from some of the calculations. This would show both extremes and more accurate riparian and land use data to pair with collected specimen data. Land uses both upstream and immediately outside of the riparian area could be examined. Some layers can even break down the composition of the trees in the riparian area. Composition may be used to further research what tree stands are the most efficient at nutrient and sediment removal.

Another step would be to create a riparian restoration plan for target areas along the streams in order to increase habitat and stream health. The field of restoration science is growing rapidly and is becoming very important to maintaining healthy ecosystems (Goodwin, 1997). Research can be done to find baselines of what riparian areas looked like before European settlers came and disturbed these areas.

Stream segments with poor riparian buffers can suffer by excess nutrients and sediment directly entering the stream by runoff, which was apparent in this study when looking at the differences between stretches. In riparian areas that were rated higher in both the RCE and WQNHA scores showed higher levels of pollution-intolerant Ephemeroptera, Plecoptera, and Tricoptera. These results demonstrate that stream health is directly affected by the health of the surrounding riparian area.

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Appendix A: Locations of each study site

Watershed	Longitute	Latitude
Fossil	-80.222547	41.803901
Rundelltown	-80.283692	41.758734
Watson	-80.262166	41.637160
Wolfhauser (Wolf)	-80.170573	41.724419

Appendix B: Front and back of Riparian, Channel, and Environmental Inventory

RIPARIAN, CHANNEL, AND ENVIRONMENTAL INVENTORY (RCE)

(modified from Petersen (1992)

BASIC DATA

Stream name: _____ **Watershed:** _____

Date: _____ **Time:** _____

EXACT Location:

_____

_____

Observers:

_____

_____

Approximate stream width: _____ **m** **Approximate stream depth:** _____ **m**

Stream flow condition: high medium low very low

Days since last significant rain: 0 1 2 3 4-7 8+

Initial Rating: excellent very good good fair poor

INVENTORY

Determine the condition of the stream I. **RIPARIAN ZONE** and II. **CHANNEL STRUCTURE** at which you are standing and up to **50 m upstream and downstream (100 m total)**. Estimate the average condition over that distance and select ONE of the four scores for each characteristic. Indicate your selection by writing an X next to your choice. Refer to the **Glossary** in the **Guide to RCE**.

I. LAND USE at the local reach scale

1. Land-use pattern beyond the immediate riparian zone
   - Undisturbed, consisting of forest and/or natural wetlands 30 _____
   - Permanent pasture mixed with woodlots and wetlands; few buildings and roads 20 _____
   - Mixed row crops and pasture, or mixed grass lawn and homes 10 _____
   - Mainly row crops, or mostly streets, pavement, buildings, and parking lots 1 _____

2. Width of riparian zone from stream edge to field
   - Marshy or woody riparian zone >30 m wide 30 _____
   - Marshy or woody riparian zone varying from 5 to 30 m 20 _____
   - Marshy or woody riparian zone 1-5m 5 _____
   - Marshy or woody riparian zone absent 1 _____

3. Completeness of riparian zone
   - Riparian zone intact without breaks in vegetation along entire 100m zone 30 _____
   - Areas without vegetation occur at intervals of > 50 m (fragmented riparian zone) 20 _____
   - Areas without vegetation frequent with some erosion (gullies and scars) every 50 m 5 _____
   - Many areas without vegetation, erosion occurring (gullies, scars) along entire length 1 _____

4. Vegetation of riparian zone within 10 m of the channel
   - >90% plant density of mature trees or shrubs, or native marsh plants 25 _____
   - Mixed young tree species along channel and mature trees behind 15 _____
   - Vegetation of mixed grasses and sparse young tree or shrub species 5 _____
   - Vegetation consisting mostly of grasses, few trees & shrubs; low plant density; 1 _____

Total for Reach Scale Riparian Land Use _____

II. PHYSICAL STRUCTURE OF STREAM

(reflects combined effects of upstream land use & riparian intactness + local riparian habitat)

5. Debris dams (fallen trees, logs, limbs, and rock material wedged in or along channel)
   - Channel with old debris dams - old logs and rocks firmly set in place 15 _____
   - Logs and rocks present but back filled with some sediment 10 _____
   - Debris dams loose, probably moving with floods 5 _____
   - Debris dams sparse, easily moved; or debris dams absent 1 _____

6. Channel Width to Depth ratio (width and depth measured as if channel was full to banks)
   - if answer is < 7 channel should be ample for present and annual peak flows 15 _____
   - if answer is 8-15; channel adequate, overbank flows rare 10 _____
   - if answer is 16-25; channel barely contains common high flows 5 _____
   - if answer is >25 or stream is artificially channelized; overbank flow common 1 _____

7. Channel bars
   - Little channel width enlargement (bank erosion, undercutting) gravel bars present 15 _____
   - Some gravel bars, pore spaces between rocks well washed with little silt present 10 _____
   - Sediment bars of rocks, sand, and silt common 5 _____
   - Channel divided into braids(*) around sediment bars; or stream is channelized(*) 1 _____

8. Stream-bank stability
   - Banks stable, of rock and soil held firmly by grasses, shrubs, and tree roots 25 _____
   - Banks firm but loosely held by grass and shrubs 15 _____
   - Banks loose, held by a sparse layer of grass and shrubs 5 _____
   - Banks unstable, of loose soil or sand easily disturbed 1 _____

9. Bank undercutting
   - Little or none evident or restricted to areas with tree root support 20 _____
   - Band undercutting(*) only on curves or narrow channel areas 15 _____
   - Band undercutting common, some banks falling in 5 _____
   - Severe bank undercutting(*) along channel, banks falling in 1 _____

10. Stony substrate: feel and appearance
   - Stones clean, rounded (smooth pebbles, cobbles); may have blackened color 25 _____
   - Stones without sharp edges and with slight gritty feel 15 _____
   - Some stones with sharp edges, obvious gritty feel 5 _____
   - Stones bright; silt and grit covering them, sharp edges common 1 _____

11. Fine sediments in riffles & runs
   - Various sized rocks, gravel, and sand mixture; open spaces common between rocks 25 _____
   - Loose stony bottom with some silt having settled in spaces between rocks 15 _____
   - Mixture of silt and fine sand; few open spaces between rocks; bottom firm in places 5 _____
   - Uniform bottom of silt & sand and silt held loosely together 1 _____

12. Riffles and pools
   - Riffles distinct, occurring at intervals of 5-7 times the stream width (not channel width) 25 _____
   - Riffles and pools irregularly spaced 20 _____
   - Long pools separating short riffles 10 _____
   - Riffles and pools absent or stream channelized 1 _____

Total for Reach Scale Riparian Land Use _____

Total RCE _____

Appendix C: Front and back of the PA Department of Environmental Protection Agency's WQNHA

3800-FM-WSFR0402 Rev. 10/2008

pennsylvania

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF WATER STANDARDS AND FACILITY REGULATION

WATER QUALITY NETWORK
HABITAT ASSESSMENT

WATERBODY NAME _____ STR CODE/RMI _____

STATION NUMBER _____ LOCATION _____

DATE _____ TIME _____

AQUATIC ECOREGION _____ COUNTY _____

INVESTIGATORS _____

FORM COMPLETED BY _____ *RIFFLE/RUN PREVALENCE*

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Instream Cover (Fish)	Greater than 50% mix of boulder, cobble, submerged logs, undercut banks, or other stable habitat.	30-50% mix of boulder, cobble, or other stable habitat; adequate habitat.	10-30% mix of boulder, cobble, or other stable habitat; habitat availability less than desirable.	Less than 10% mix of boulder, cobble, or other stable habitat; lack of habitat is obvious.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
2. Epifaunal Substrate	Well developed riffle and run, riffle is as wide as stream and length extends two times the width of stream; abundance of cobble.	Riffle is as wide as stream but length is less than two times width; abundance of cobble; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than two times the stream width; gravel or large boulders and bedrock prevalent; some cobble present.	Riffles or run virtually nonexistent; large boulders and bedrock prevalent; cobble lacking.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
3. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
4. Velocity/Depth Regimes	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow).	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score lower than if missing other regimes).	Dominated by 1 velocity/depth regime (usually slow-deep).
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
5. Channel Alteration	No channelization or dredging present.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	New embankments present on both banks; and 40-80% of stream reach channelized and disrupted.	Banks shored gabion or cement; over 80% of the stream reach channelized and disrupted.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Total Side 1 _____				

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RIFFLE/RUN PREVALENCE

Habitat Parameter	Category				
	Optimal	Suboptimal	Marginal	Poor	
6. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from coarse gravel; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, coarse sand on old and new bars; 30-50% of the bottom affected; sediment deposits at obstruction, constriction, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
7. Frequency of Riffles	Occurrence of riffles relatively frequent; distance between riffles divided by the width of the stream equals 5 to 7; variety of habitat.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream equals 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is between ratio >25.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
8. Channel Flow Status	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.	Water fills > 75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
9. Condition of Banks	Banks stable; no evidence of erosion or bank failure.	Moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in reach have areas of erosion.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; on side slopes, 60-100% of bank has erosional scars.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
10. Bank Vegetative Protection	More than 90% of the streambank surface covered by vegetation.	70-90% of the stream-bank surface covered by vegetation.	50-70% of the stream-bank surfaces covered by vegetation.	Less than 50% of the streambank surface covered by vegetation.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
11. Grazing or Other Disruptive Pressure	Vegetative disruption, through grazing or mowing, minimal or not evident; almost all plants allowed to grow naturally.	Disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	Disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Disruption of vegetation is very high; vegetation has been removed to 2 inches or less in average stubble height.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
12. Riparian Vegetative Zone Width	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.	
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1	
Total Side 2 _____					
Total Score _____					