Muddy Creek Aquatic Ecosystem

Summary Report

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Prepared for:

Friends of the Cheat

River of Promise

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Executive Summary

The Muddy Creek watershed is severely impacted from acid mine drainage (AMD), and poses a major source of pollution to the lower Cheat River. Monitoring the health of the Muddy Creek watershed regularly over the long term is absolutely essential for the development of comprehensive science-based management plans. The overriding objective of this report was to provide a summary of the current stream ecosystem conditions in the Muddy Creek watershed encompassing data collected from 2002 – 2014. The information and analysis from this report will be included in the development of the updated watershed-based restoration plan for the Muddy Creek watershed. Water chemistry and biological conditions varied widely throughout the Muddy Creek watershed. This summary report documented significant impairments at study sites below where Martin Creek joins the Muddy Creek mainstem. Our sampling noted improvements in water quality in 2012 most likely attributed to the in-stream doser operating on Fickey Run. Unfortunately, this treatment system went off-line after the 1-year demonstration period elapsed, and watershed-scale improvements were short lived. Despite the highly degraded ecological conditions from AMD in the lower portion of the drainage, upper Muddy Creek remains a high quality trout fishery. Watershed-based restoration plans focused on protecting and restoring upper Muddy Creek, as well as reconnecting the watershed to the lower Cheat River will serve a major societal benefit both ecologically and economically.

Introduction

Muddy Creek is located in Preston County, WV and joins the Cheat River near Albright, WV. In March of 1994, a mine blowout occurred at the T & T mine complex near the confluence of Martin Creek and Muddy Creek (Figure 1 and 2). This blowout occurred above the mine seal, devastating aquatic ecosystems, and producing acid mine drainage (AMD) flows of 25,000 gallons per minute for 3 – 4 days. These acidic drainages entered Muddy Creek, a tributary to the Cheat River, posing a major source of pollution. A second blowout occurred similar to the first in April of 1995. Needless to say, the Muddy Creek watershed is severely impacted by AMD, and has several current remediation projects, or projects in the works, designed to improve water quality by neutralizing acidic drainage.

The Muddy Creek watershed has been monitored yearly from 2002 to 2014 to track aquatic ecosystem conditions. This monitoring included regular water quality and benthic macroinvertebrate sampling, all focused to assess and quantify potential watershed-scale improvements from AMD treatment projects in the Muddy Creek watershed. Watershed-based plans are required to effectively manage, protect, and restore stream networks that are under the influence of multiple potential stressors such as AMD. Monitoring the health of stream ecosystems regularly over the long term is absolutely essential for the development of these comprehensive science-based management plans.

In 2012, an in-stream active treatment doser was operating on Fickey Run, a tributary to Martin Creek. This doser added a hydrated lime slurry directly to the impaired waters. This addition of alkaline material to acidic waters increases the pH, consequently precipitating out the dissolved metals. However, the project was only planned to be a temporary demonstration project supported by the United States Environmental Protection Agency (USEPA) and the West

Virginia Department of Environmental Protection (WVDEP). After the 1-year demonstration period elapsed, the dosing effort was stopped.

The overriding objective of this report is to provide a comprehensive summary of the current stream ecosystem conditions in the Muddy Creek watershed encompassing water chemistry and benthic macroinvertebrate community data collected from 2006 – 2014, fish abundance data collected from 2002, 2008, and 2013-2014, and physical habitat data collected from 2008, 2013, and 2014. The information and analysis from this report will be included in the development of the updated watershed-based restoration plan for the Muddy Creek watershed.

Methods

Study Area

Muddy Creek is an 87-km^2 watershed (lower Cheat River basin) located in Preston County, West Virginia (Figure 1). The geology of the watershed consists predominantly of shale and sandstone (Figure 3), and the land cover is dominated by forest. Impairments throughout the watershed are primarily due to AMD from legacy coal mining (Figure 2). A total of 43.5 stream km are impacted by AMD in the Muddy Creek drainage. According to the Total Maximum Daily Load (TMDL) published by WVDEP in 2011, the Muddy Creek watershed contributes an estimated 1564 tons/year of acidity, 294 tons/year of iron, and 153 tons/year of aluminum.

We studied 7 sites along the Muddy Creek river continuum for chemical, biological, and physical habitat conditions (Figure 1, Table 1). Water chemistry and benthic macroinvertebrate communities have been monitored each spring from 2006 – 2014. The Upper Muddy Creek site has been monitored since 2008, and the Muddy Creek at Brandonville Pike site has been monitored since 2013. This location was added to the long term sites to obtain baseline prerestoration data essential to evaluate the presumed post-restoration benefits of the passive treatment system being installed near Brandonville Pike in September 2014.

Fish abundance data were collected during the summer. In 2002, fish were monitored at assessment sites above the confluence of Martin Creek and the Muddy Creek mainstem. In 2008, fish abundance data were collected at the Muddy Creek at Million Dollar Bridge site and the Upper Muddy Creek site, and all sites on the mainstem above Martin Creek were sampled for fish from 2013-2014. Sites on Muddy Creek downstream of the Martin Creek confluence were assumed not to have fish and therefore were not sampled.

Finally, habitat in Muddy Creek was assessed using rapid bioassessment protocols. Rapid visual habitat assessment (RVHA) parameters were collected in the summer of 2008 at the Muddy Creek above Crab Orchard Run site, Million Dollar Bridge site, and Upper Muddy Creek site. In the summer of 2013 at all sites above the Martin Creek confluence were assessed for habitat, and in the summer of 2014 all mainstem sites were assessed.

Data Collection

Physicochemical

Water chemistry was monitored at assessment sites by collecting a l-liter unfiltered grab sample and a 500-mL filtered sample (0.45 µm pore sized filter membrane). Filtered samples were treated immediately with nitric acid to prevent dissolved metals from precipitating. All samples were kept on ice after collection and stored at 4°C until analyses were completed. These collected samples were analyzed at the National Research Center for Coal and Energy at West Virginia University for alkalinity (mg/L $CaCO_3$ equivalents), acidity (mg/L $CaCO_3$ equivalents), sulfate (mg/L SO_4), total suspended solids, and total dissolved aluminum, barium, copper, chloride ion, cobalt, chromium, cadmium, calcium, sodium, nickel, selenium, zinc, iron, magnesium, and manganese concentrations (mg/L). In addition, temperature (°C), pH, specific conductance (µS/cm), dissolved oxygen (mg/L), and total dissolved solids (g/L) were measured in the field using a YSI 650 with a 600 XL sonde (Yellow Springs, OH). Stream discharge was measured using the area-velocity technique with a Marsh-McBirney Flo-Mate 2000 flow meter (Marsh-McBirney, Frederick, MD). Physical habitat condition was evaluated with rapid visual habitat assessment (RVHA) techniques following USEPA protocols (Barbour et al. 1999). Parameters were measured by the same observer within years to maximize repeatability and reduce errors in the data (Roper and Scharnecchia 1995, Freund and Petty 2007).

Benthic Macroinvertebrates and Fishes

Biological condition was monitored by collecting benthic macroinvertebrate and fish abundance data. Benthic macroinvertebrates were sampled following rapid bioassessment protocols for wadeable rivers (Barbour et al. 1999). At each site four kick samples were obtained using a rectangular style kick-net (net dimensions 355 x 508 mm with 500 µm netting) from widely separated riffle habitat to get a 1.0 m^2 total kick area. All four samples were filtered through a 250 µm sieve, combined into a single composite sample, and preserved in 95% ethanol. Subsampling followed a modified version of the USEPA's Rapid Bioassessment Protocol. All macroinvertebrates were identified to genus or the lowest possible taxonomic level using Peckarsky et al. (1990) and Merritt and Cummins (2008).

To monitor fish abundance 1 to 2 backpack electrofishing units (Smith Root models 12-B, 15-D, and/or LR-24) were used depending on the size of the stream (Freund and Petty 2007). Assessment site reaches were 40 times the mean stream width or a minimum of 150 m and a maximum of 300 m in length. All individuals captured were identified to species and returned to the stream alive after completion of the assessment site.

Data Analysis

Water chemistry and physical habitat data were compiled statistically by site to characterize the mean and standard deviation for each parameter. Water quality data for 2012 were pull out of the long-term mean calculations, because of the operation of the doser on Ficky Run during that year. Data for 2012 are presented along-side the long-term mean calculated for all other years combined. Benthic macroinvertebrate and fish abundance data for each site were analyzed using a variety of community metrics, and indexes of biotic integrity (IBI), including total family and genus richness, EPT family and genus richness, West Virginia Stream Condition Index (WVSCI), and the Genus Level Index of Most Probable Stream Status (GLIMPSS) for macroinvertebrates, and species richness, specific taxa richness, and composition for fish. For habitat, we complied data for each of the 10 rapid visual habitat parameters individually (Table 5) and also summed them for a total score for each site. The maximum RVHA score a site could receive is 200 (range 0 – 200), but we scaled total scores to 100 to ease interpretation and comparability across sites in terms of percentages. All analyses were also completed for comparison purposes with respect to AMD treatment in 2012 at Fickey Run, a tributary to Martin Creek. All statistical analyses were conducted in the R statistical environment Version 3.0.2 (R Development Core Team 2013).

Results and Discussion

Muddy Creek Physicochemical Conditions

Water chemistry was highly variable throughout the watershed. Figure 5a shows the long-term mean for the two sites in the lower portion of the drainage (Muddy Creek mouth and Muddy Creek above Crab Orchard Run) below the lower limit of the pH threshold for West Virginia state standards. These 2 sites are the most impaired from AMD due to legacy mining. In 2012 our sampling noted an increase in pH at these sites most likely due to treatment from the in-stream doser on Fickey Run. Particularly, the pH of Muddy Creek mouth was observed above the lower limit of 6 with a pH of 6.52 (Table 2). Similar trends in 2012 are observed in Figures 5b and 5c in comparison to the long-term means such as increases in alkalinity and decreases in acidity. Figure 5d shows the two sites receiving treatment in 2012 below the EPA guidance level of 500 μS/cm for specific conductivity (Pond et al. 2008), where the long-term means for these sites are above this threshold. Figures 6a-d shows that in 2012 during the time the Fickey Run doser was in operation, aluminum, sulfate, iron, and manganese concentrations were all observed below the long-term means for the 2 sites receiving treatment in the lower portion of the Muddy Creek drainage.

Upper Muddy Creek is observed to have highest long-term mean for alkalinity in the watershed (Figure 5b, Table 1). This degree of alkalinity compared to the other assessment sites is most likely a result of the underlying limestone geology (Figure 3). Natural limestone outcropping here has a greater capacity to buffer acid deposition compared to the shale and sandstone geology found throughout the rest of the watershed.

Further downstream from the most upstream sampling location (Upper Muddy Creek), limestone sand is dumped near the mouth of Jump Rock Run at a dirt road crossing (Figure 1). Limestone sand application is performed by dumping sand along the impacted tributary’s stream bank where gravity and stream water gradually wash the sand downstream adding alkalinity and raising pH. This tributary, Jump Rock Run, has an underlying geology of sandstone. Sandstones have no alkalinity, and therefore have no capacity to buffer acid deposition. The long-term trend on Muddy Creek at Cuzzart does not show any additional lift in alkalinity downstream from the limestone sand dump site at Jump Rock Run. The limestone sand being applied here is most likely neutralizing the acid deposition from Jump Rock Run helping to keep the acidity lower in the upper Muddy Creek drainage, above where Martin Creek joins the mainstem.

Working in the downstream direction starting at the Upper Muddy Creek site, the overall water quality is good and supports a healthy trout fishery. However, below where Martin Creek joins the Muddy Creek mainstem water quality declines dramatically, except for a brief period of time in 2012 where water quality most likely improved from the active in-stream doser operating on Fickey Run. Physical habitat condition throughout the watershed did not vary as widely as water chemistry and biological conditions. Generally, all sites had fair scores for habitat quality (between 79.0 – 87.8%) except for Muddy Creek at Brandville Pike, which had a score of 70.5 (Table 5). The lower score here, although not exceeding low, may be hard to interpret but could be due to the lower quality riparian zone, weak bank stability, and embeddedness in this area. Consequently, we conclude that it is the water quality that is, by far, the major limiting factor in the Muddy Creek watershed, and not habitat, which is a common observation for riverine ecosystems in this mining district of WV (Merovich and Petty 2010).

Muddy Creek Biota

Benthic macroinvertebrate communities varied widely throughout the Muddy Creek mainstem. Similar to water chemistry, invertebrate communities at Muddy Creek mouth and Muddy Creek above Crab Orchard Run are the most impaired. Both of these sites scored below the impairment threshold for benthic macroinvertebrate indexes of biotic integrity at both the family-level (Figure 7d) and the genus-level (Figure 8d). However, unlike the positive response of water chemistry to treatment in 2012, benthic macroinvertebrate communities did not response in a similar fashion. This is most likely due to the gradual nature of benthic macroinvertebrate recolonization after disturbance. Several studies have observed little to no recovery and delayed recovery in benthic macroinvertebrate communities following restoration efforts (Bradely and Ormerod 2002, LeFevre and Sharpe 2002, Simmons et al. 2005, Gunn et al. 2010, Louhi et al. 2011).

Upstream from these 2 degraded sites, above where Martin Creek joins the mainstem, benthic macroinvertebrate communities improve greatly at both the family- and genus-level. For example, at the family-level the percent of Ephemeropterans (Mayflies) (Figure 7a), EPT (Mayflies, Stoneflies, and Caddisflies) family richness (Figure 7b), total aquatic invertebrate family richness (Figure 7c), and West Virginia Stream Condition Index (WVSCI) scores (Figure 7d) increase to much healthier levels. At the genus-level, Ephemeropteran genus richness (Figure 8a), Plecopteran (Stonefly) genus richness (Figure 8b), total aquatic invertebrate genus richness (Figure 8c), and the Genus Level of Most Probable Stream Status (GLIMPSS) scores (Figure 7d) improve, indicating healthier and more diverse aquatic invertebrate assemblages.

Although benthic macroinvertebrate communities at assessment sites above where Martin Creek enters the stream continuum improve, our results suggest that the Brandonville Pike site is impaired. This is evident in Figure 8d, which shows the mean GLIMPSS score below the impairment threshold of 62 as defined by the WVDEP. The first occurrence of AMD from legacy coal mining appears in the Muddy Creek mainstem just before it crosses under the Brandonville Pike. Acidic drainages here seep into Muddy Creek from an abandoned mine land on the north bank of the stream (Figure 2). A passive treatment system is being installed here to treat these acidic discharges with limestone. Treated water will then pass through a wetland before entering Muddy Creek. This project is anticipated to be completed by the end of September 2014.

At this site (Brandonville Pike at Muddy Creek), the benthic macroinvertebrate community is depressed, unlike the fish community which does not show such obvious signs of impairment. One explanation for this is that benthic macroinvertebrates are good indicators of local conditions (Freund and Petty 2007). Their sedentary nature allows for the effective determination of the spatial extent of environmental stress, and their long life cycles allow for temporal changes in community structure to be examined (Rosenberg et al. 2008). On the other hand, fish are good indicators of regional conditions due to their high mobility and long lives (Freund and Petty 2007). Benthic macroinvertebrates at the Brandonville Pike site are locally impaired from the AMD seeping into Muddy Creek at the proposed restoration project site. The fish community shows more of a regional response to the overall good quality of the upper Muddy Creek watershed. Together, the biological monitoring of both these communities are valuable for diagnosing historic and chronic stressors, the effects of aquatic habitat fragmentation, and stressors that have local and regional impacts (Freund and Petty 2007). The passive treatment system being installed near the Brandonville Pike site should improve the local conditions, ensuring the future regional health of upper Muddy Creek as a trout fishery. Post-restoration monitoring of this site and the entire Muddy Creek stream continuum is needed to determine if the passive treatment system installed improves the chemical and biological integrity of the upper Muddy Creek watershed.

Fish communities also varied widely throughout the Muddy Creek mainstem. Fish were assumed not present in the Muddy Creek at mouth site or the Muddy Creek above Crab Orchard

Run site due to the acidic, metal laden chemical conditions and the extremely poor benthic macroinvertebrate IBI scores observed here. We did observe fish at all other assessment sites above where Martin Creek joins Muddy Creek. Despite the highly degraded ecological conditions from AMD in the lower portion of the drainage, upper Muddy Creek (above where Martin Creek joins the mainstem) remains a high quality trout fishery. Figure 11d shows the percent of the fish community comprised of trout for each assessment site. The high variability around the mean for the Muddy Creek at Million Dollar Bridge site was due to a large number of brown trout fingerlings observed in 2014 from a recent stocking event. However, larger trout such as brown and rainbow trout were also found here. The largest trout observed was a rainbow trout measuring in at a total length of 560 mm or 22 in. This fish was found at the Muddy Creek at Cuzzart site along with many other large brown and rainbow trout. The largest brook trout we observed was at the Tack Shop at Muddy Creek site (Figure 4). Three brook trout were found here over 450 mm. Trout were found at all assessment sites above where Martin Creek joins the Muddy mainstem.

Species richness was highest at the Muddy Creek at Tack Shop site (Figure 11c), and the highest fish abundance was observed at the Muddy Creek at Million Dollar Bridge site (Figure 11b). The proportion of the fish community comprised of sculpin increased along the stream continuum in the upstream direction to a high mean of 71% at the Upper Muddy Creek site (Figure 9c, Table 4). Figure 10a shows the proportion of tolerant fish comprising the community declining in the upstream direction to a low mean of 26% at the Upper Muddy Creek site (Table 4). These trends are most likely a result of higher quality water higher up in the watershed. Overall, biological and chemical conditions are best in the headwaters of Muddy Creek. Conditions gradually decline in the downstream direction along the stream continuum from acid deposition and acid mine drainage inputs until they become almost devoid of all life below where Martin Creek enters the mainstem. To ensure the future health of upper Muddy Creek as a trout fishery, acidic drainages from abandoned mine lands and bond forfeited mine sites need to be addressed.

Conclusion

In conclusion, we were able to characterize the long-term chemical, biological, and physical integrity of the Muddy Creek mainstem. This long-term monitoring of ecological conditions throughout the watershed showed that chemical and biological conditions transition from a high quality trout fishery in the headwaters to a highly degraded, functionally failing ecological habitat in the lower portion of the watershed. Significant impairments were observed at study sites below where Martin Creek joins the Muddy Creek mainstem. Our results suggest that the improvements observed in water quality at these 2 sites in 2012 are most likely attributed to the in-stream doser on Fickey Run. However, we did not observe a positive response in benthic macroinvertebrate communities at the 2 sites receiving AMD treatment. This is most likely due to the short timeframe the doser was in operation and the gradual nature of benthic macroinvertebrate recolonization. Water chemistry and biological conditions above this confluence improve dramatically. For example, trout were found at all assessment sites in the upper Muddy Creek watershed. Restoration efforts focused on addressing AMD from legacy coal mining are imperative to protecting and enhancing upper Muddy Creek.

Monitoring the health of Muddy Creek regularly over the long term is absolutely essential for the development of comprehensive science-based management plans designed to improve the aquatic ecological conditions of Muddy Creek and the lower Cheat River. The information and analysis from this report will be included in the development of the updated watershed-based plan for the Muddy Creek drainage. Watershed-based plans aimed at reconnecting upper Muddy Creek to the lower Cheat River will serve a major societal benefit both ecologically and economically.

Literature Cited

Barbour M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling.1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Bradley D., and S. Ormerod. 2002. Long-term effects of catchment liming on invertebrates in upland streams. Freshwater Biology **47**(1):161-171.

Freund, J. G., and J. T. Petty. 2007. Response of fish and macroinvertebrate bioassessment indices to water chemistry in a mined Appalachian watershed. Environmental Management **39**:707-720.

Gunn J., C. Sarrazin-Delay, B. Wesolek, A. Stasko, and E. Szkokan-Emilson. 2010. Delayed recovery of benthic macroinvertebrate communities in junction Creek, Sudbury, Ontario, after the diversion of acid mine drainage. Human and Ecological Risk Assessment **16**(4):901-912.

LeFevre S., and W. Sharpe. 2002. Acid stream water remediation using limestone sand on bear run in southwestern Pennsylvania. Restoration Ecology **10**(2):223-236.

Louhi P., H. Mykrä, R. Paavola, A. Huusko, T. Vehanen, A. Mäki-Petäys, and T. Muotka. 2011. Twenty years of stream restoration in Finland: little response by benthic macroinvertebrate communities. Ecological Applications **21**(6):1950-1961.

Merovich, G. T., Jr. and J. T. Petty. 2010. Continuous response of benthic macroinvertebrate assemblages to a discrete disturbance gradient: consequences for diagnosing stressors. Journal of the North American Benthological Society **29**:1241-1257.

Merritt, R. W., and K. W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Pub. Co, Dubuque, Iowa.

Peckarsky, B. L., P. R. Fraissinet, M. A. Penton, and D. J. Conklin. 1990. Freshwater Macroinvertebrates of Northeastern North America. Cornell University Press, Ithaca, New York.

Pond G. J., M. E. Passmore, F. A. Borsuk, L. Reynolds, and C. J. Rose. 2008. Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. Journal of the North American Benthological Society **27**(3):717-737.

R Development Core Team. 2013. R: A language and environment for statistical computing. 3.0.2.

Roper B., and D. Scarnecchia. 1995. Observer variability in classifying habitat types in stream surveys. North American Journal of Fisheries Management **15**(1):49-53.

Rosenberg D. M., V. H. Resh, and R. S. King. 2008. Use of aquatic insects in biomonitoring. In: R. W. Merritt, K. W. Cummins, and M. Berg, editors. An introduction to the aquatic insects of North America, 4th edition. Kendall/Hunt, Dubuque, IA.

Simmons J. A., E. R. Lawrence, and T. G. Jones. 2005. Treated and untreated acid mine drainage effects on stream periphyton biomass, leaf decomposition, and macroinvertebrate diversity. Journal of Freshwater Ecology **20**(3):413-424.

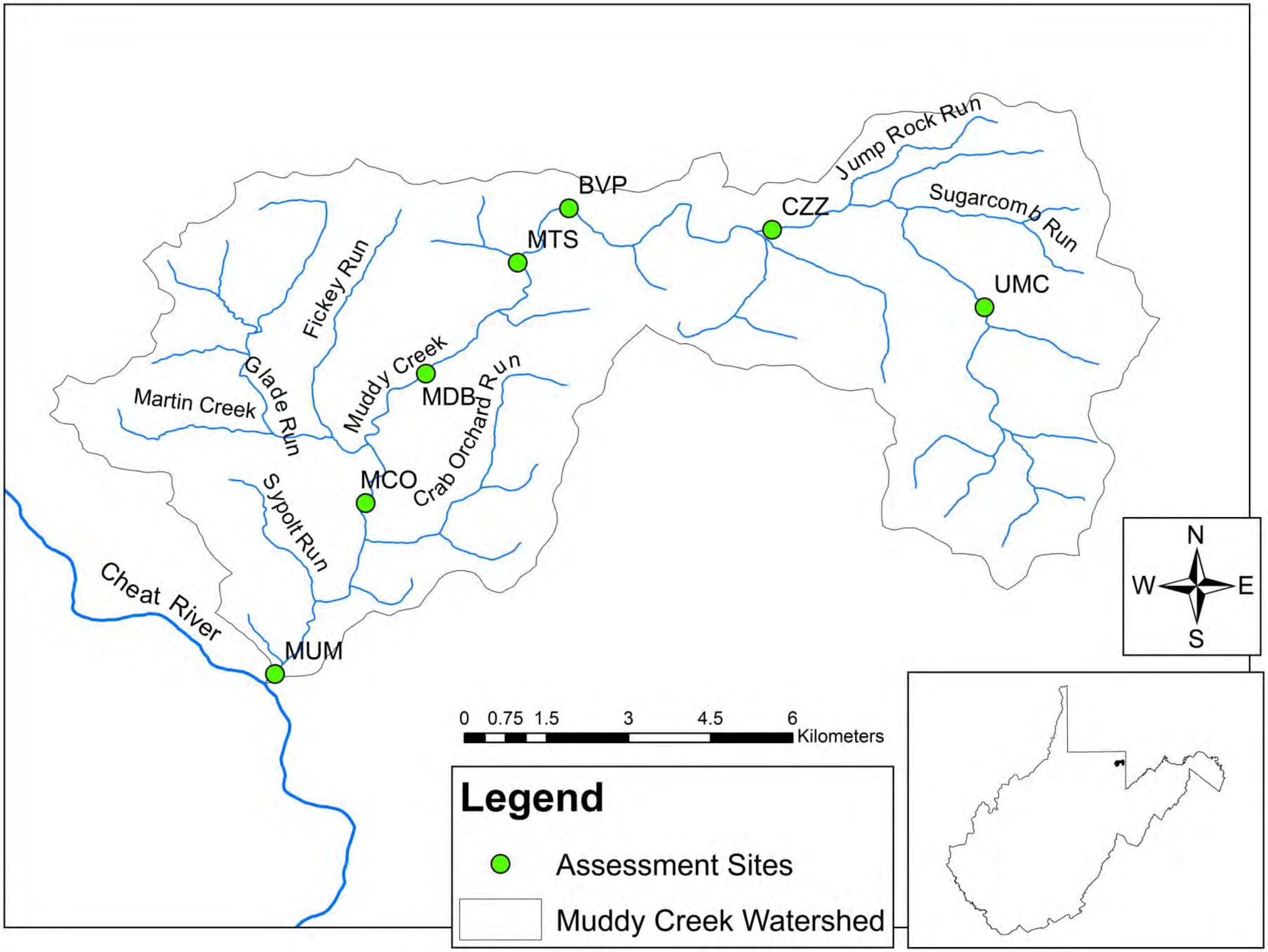


Figure 1. Map of Muddy Creek watershed in northern West Virginia along with locations of assessment sites along the Muddy Creek river continuum. Site abbreviations as in Table 1.

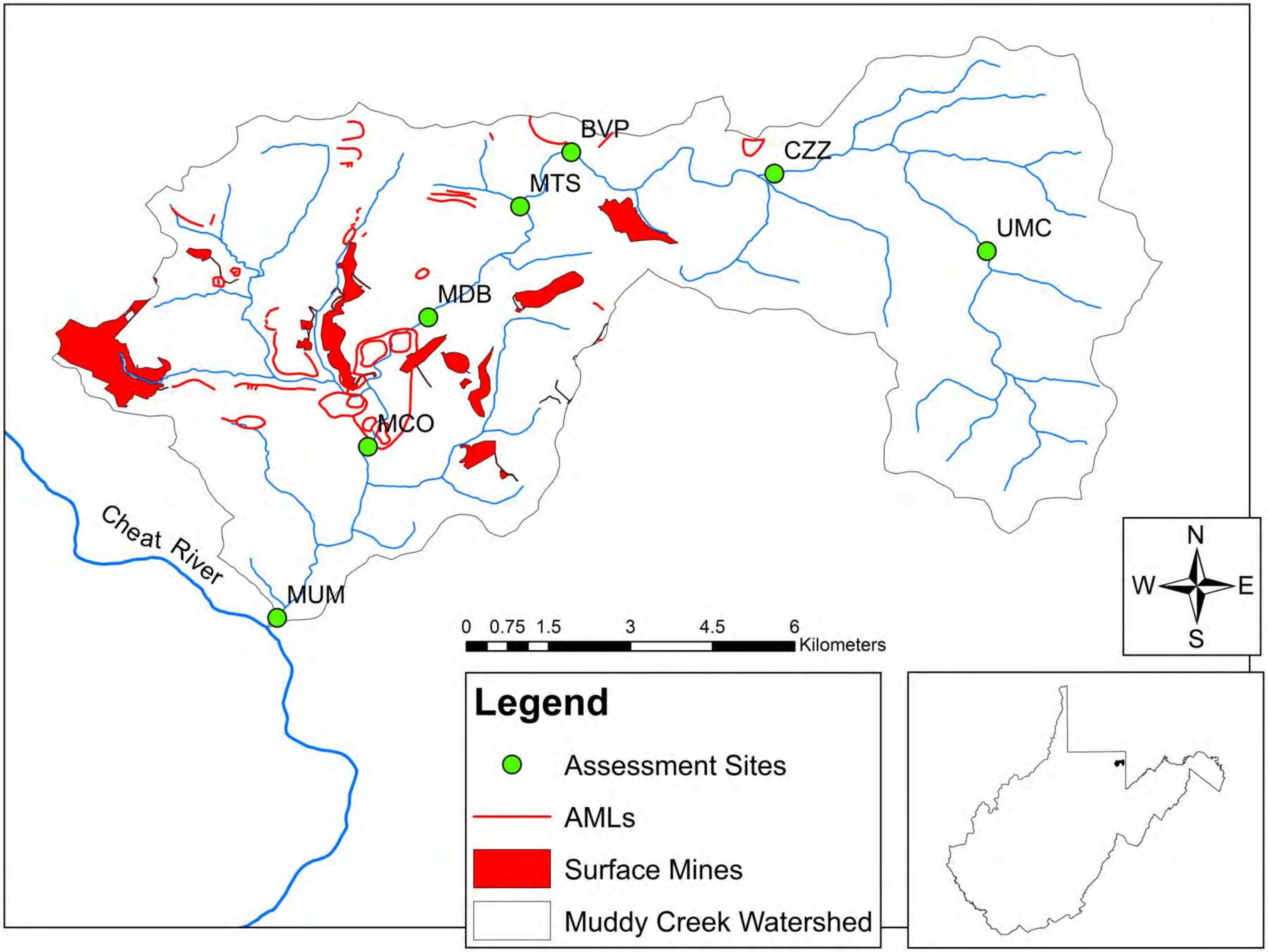


Figure 2. Abandoned mine lands (AMLs) and surface mine locations in the Muddy Creek watershed. Site abbreviations as in Table 1.

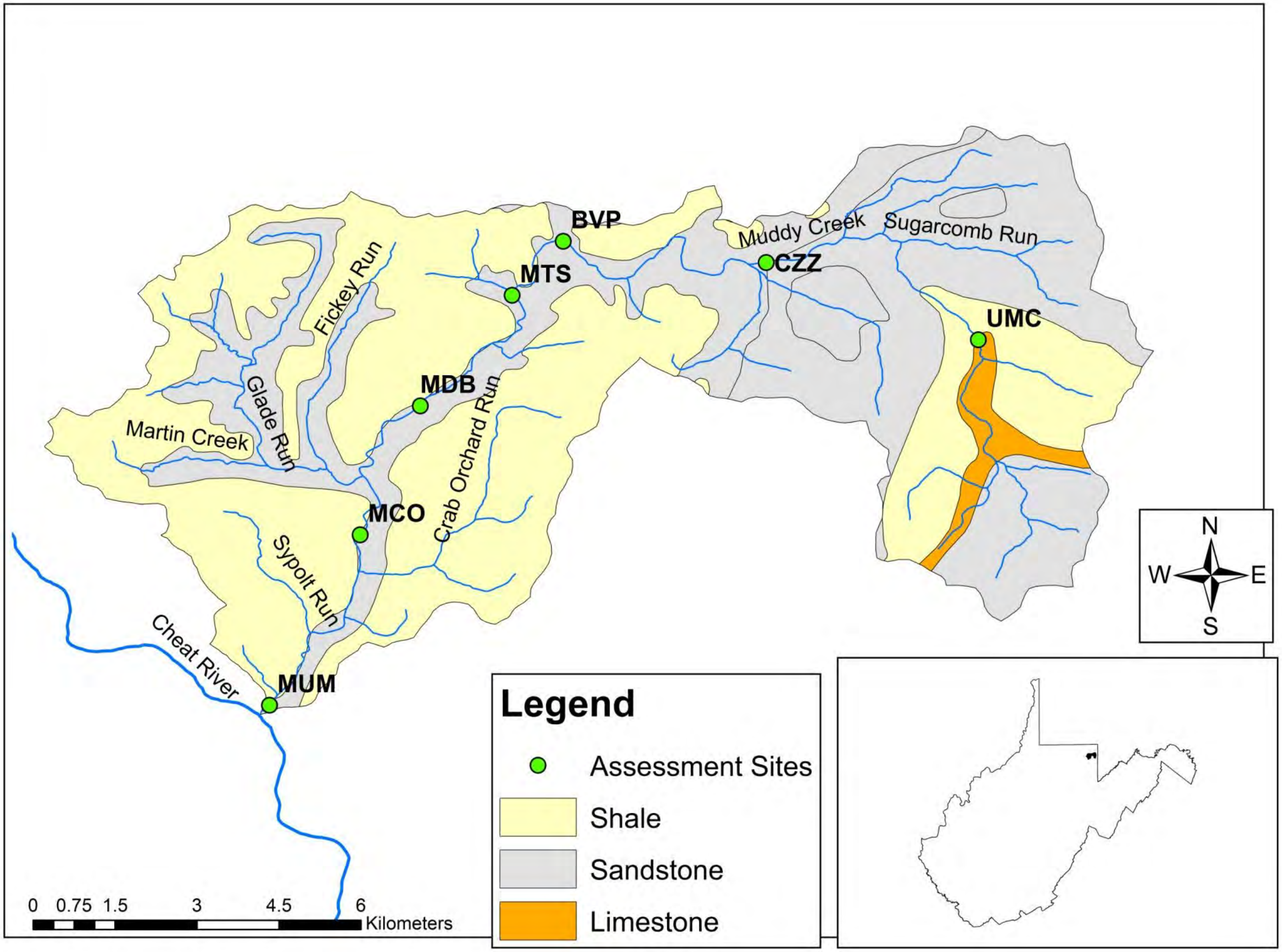
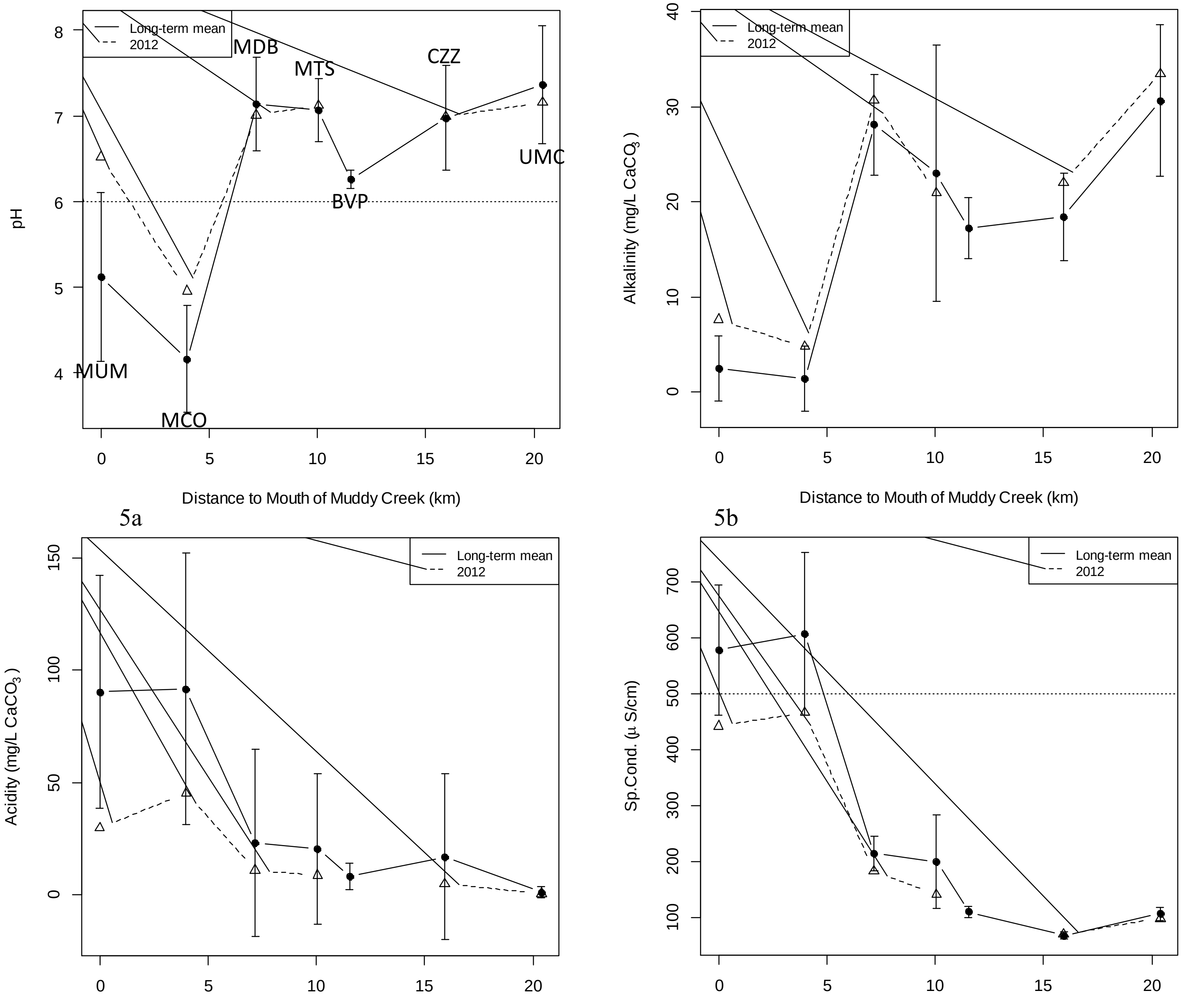


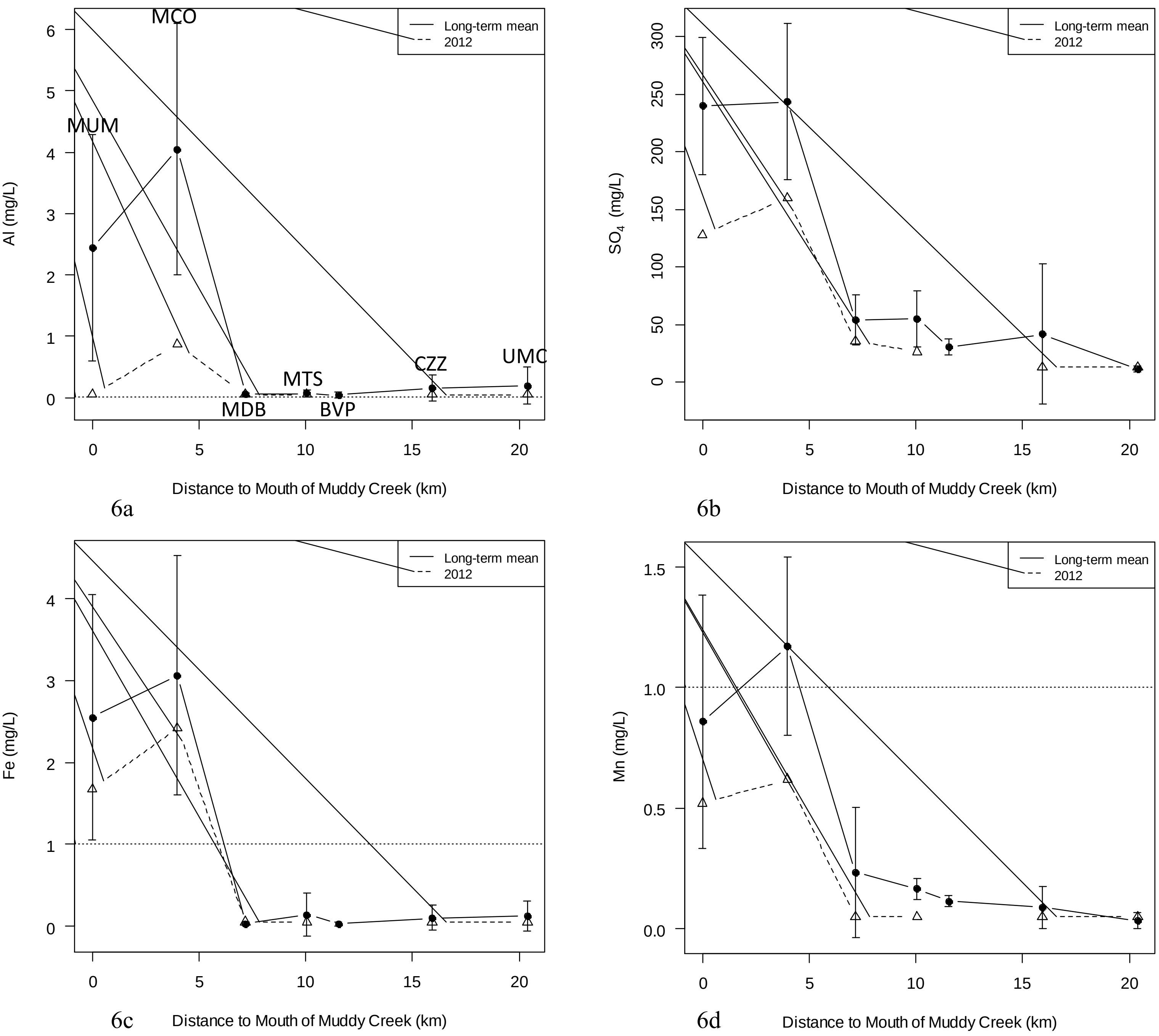
Figure 3. Geology of the Muddy Creek watershed. Site abbreviations as in Table 1.

Figure 4: Brook trout observed at the Tack Shop at Muddy Creek site. Total length = 513 mm or 20.2 in.



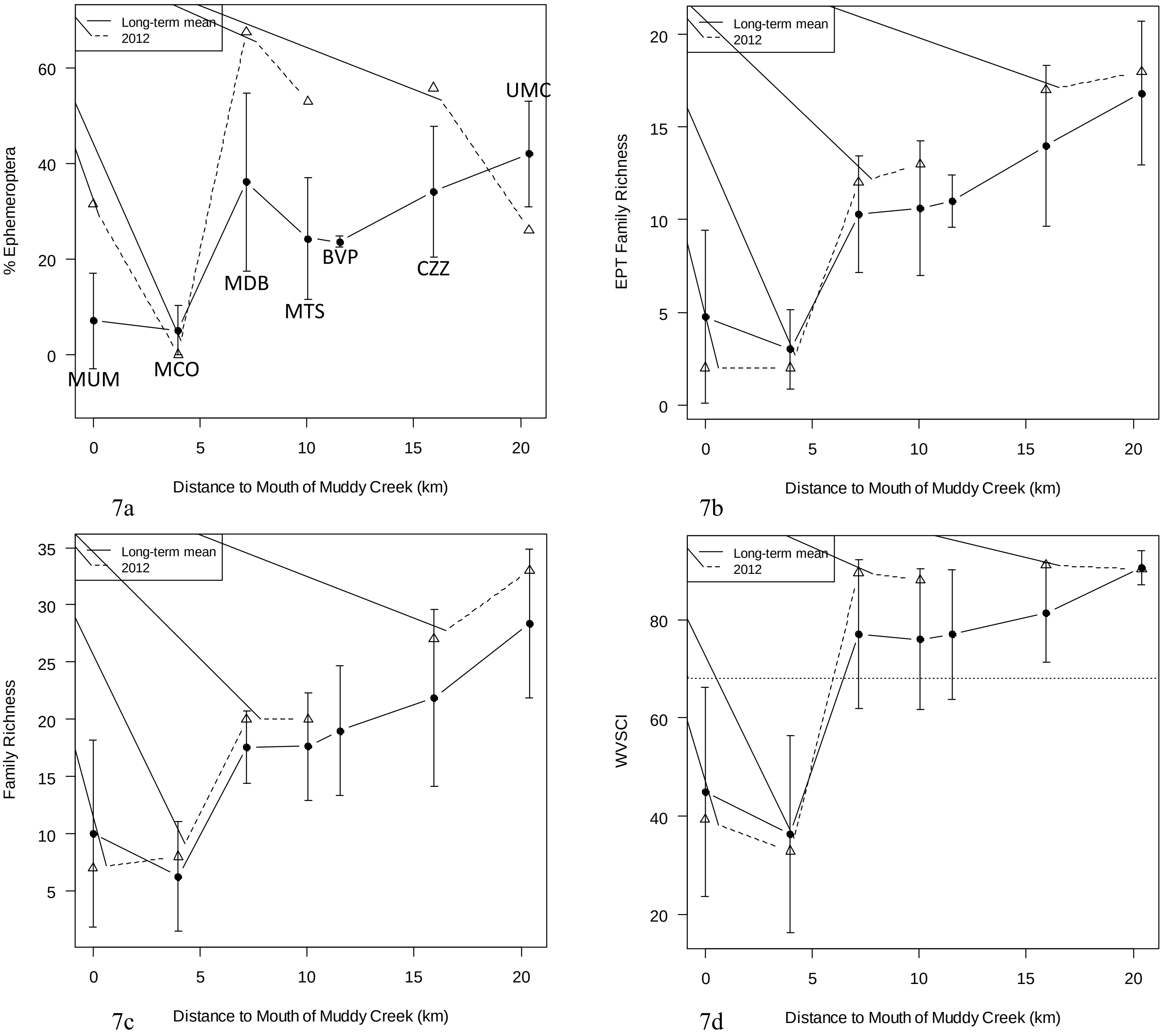
5a 5b 5c 5d

Figure 5a-d. pH (a), alkalinity (b), acidity (c), and specific conductivity (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2006-2011 and 2013-2014 data. Data from 2012 is pulled out due to AMD-treatment occurring during this sampling period on Fickey Run. The horizontal line in Figure 5a represents West Virginia state standards for the lower limit of pH. The horizontal line in Figure 5d represents the EPA guidance level for specific conductivity (Pond et al. 2008). Site abbreviations as in Table 1.



6a 6b 6c 6d

Figure 6a-d. Concentrations of aluminum (a), sulfate (b), iron (c), and manganese (d) along the Muddy Creek Stream continuum. Error bars represent standard deviation about the long-term mean for 2006-2011 and 2013-2014 data. Data from 2012 is pulled out due to AMD-treatment occurring during this sampling period on Fickey Run. The horizontal lines represent West Virginia state standards for that chemical constituent. Site abbreviations as in Table 1.



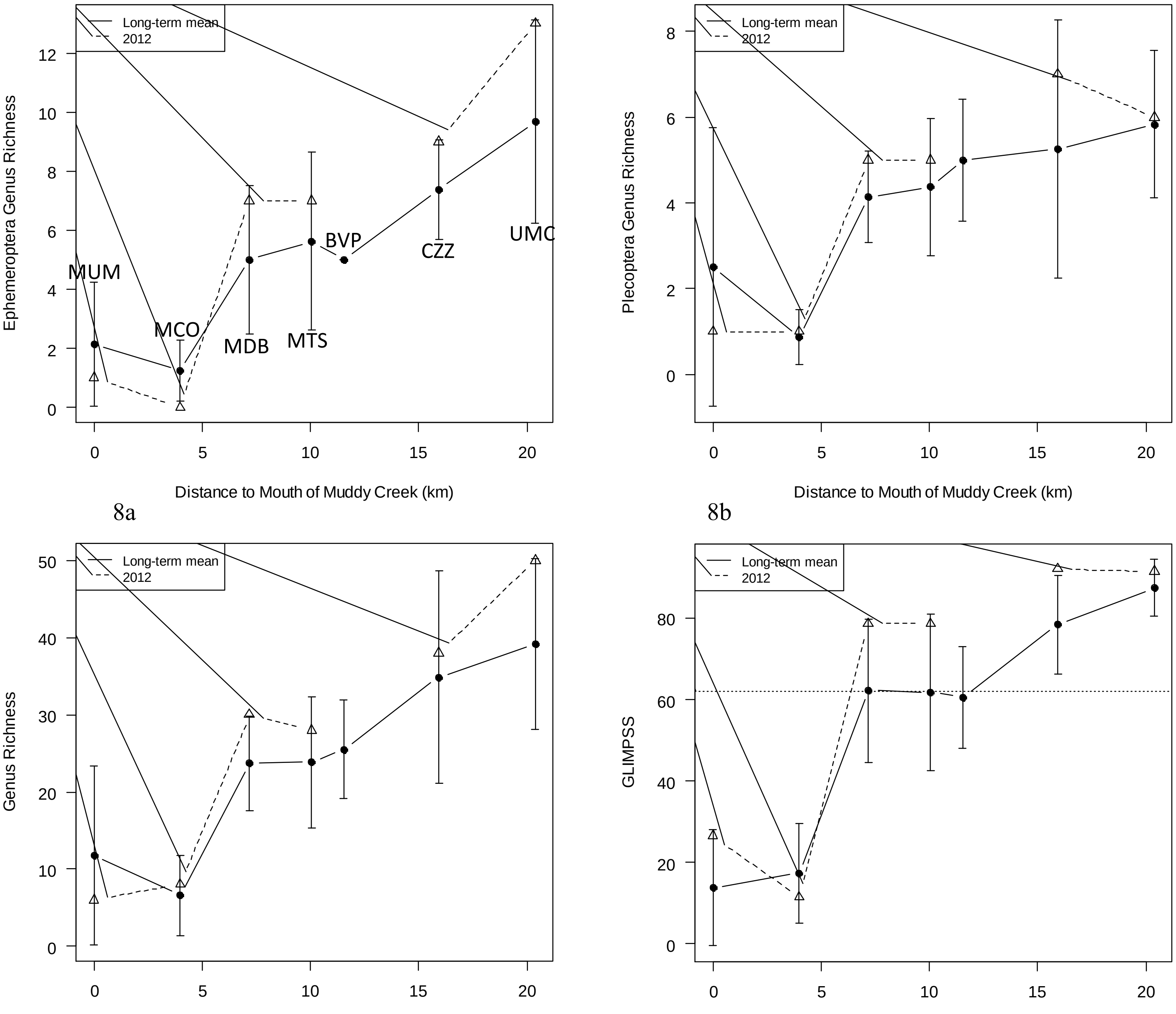
7a

7b

7c

7d

Figure 7a-d. Percent of macroinvertebrate community comprised of the order Ephemeroptera (a), the number of macroinvertebrate families that belong to the orders Ephemeroptera, Plecoptera, and Trichoptera (b), the total number of macroinvertebrate families present in the benthic community (c), and the West Virginia Stream Condition Index (WVSCI) scores (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2006-2011 and 2013-2014 data. Data from 2012 is pulled out due to AMD-treatment occurring during this sampling period on Fickey Run. The horizontal line in Figure d represents the impairment threshold for WVSCI (68.0) as defined by the WVDEP. Site abbreviations as in Table 1.



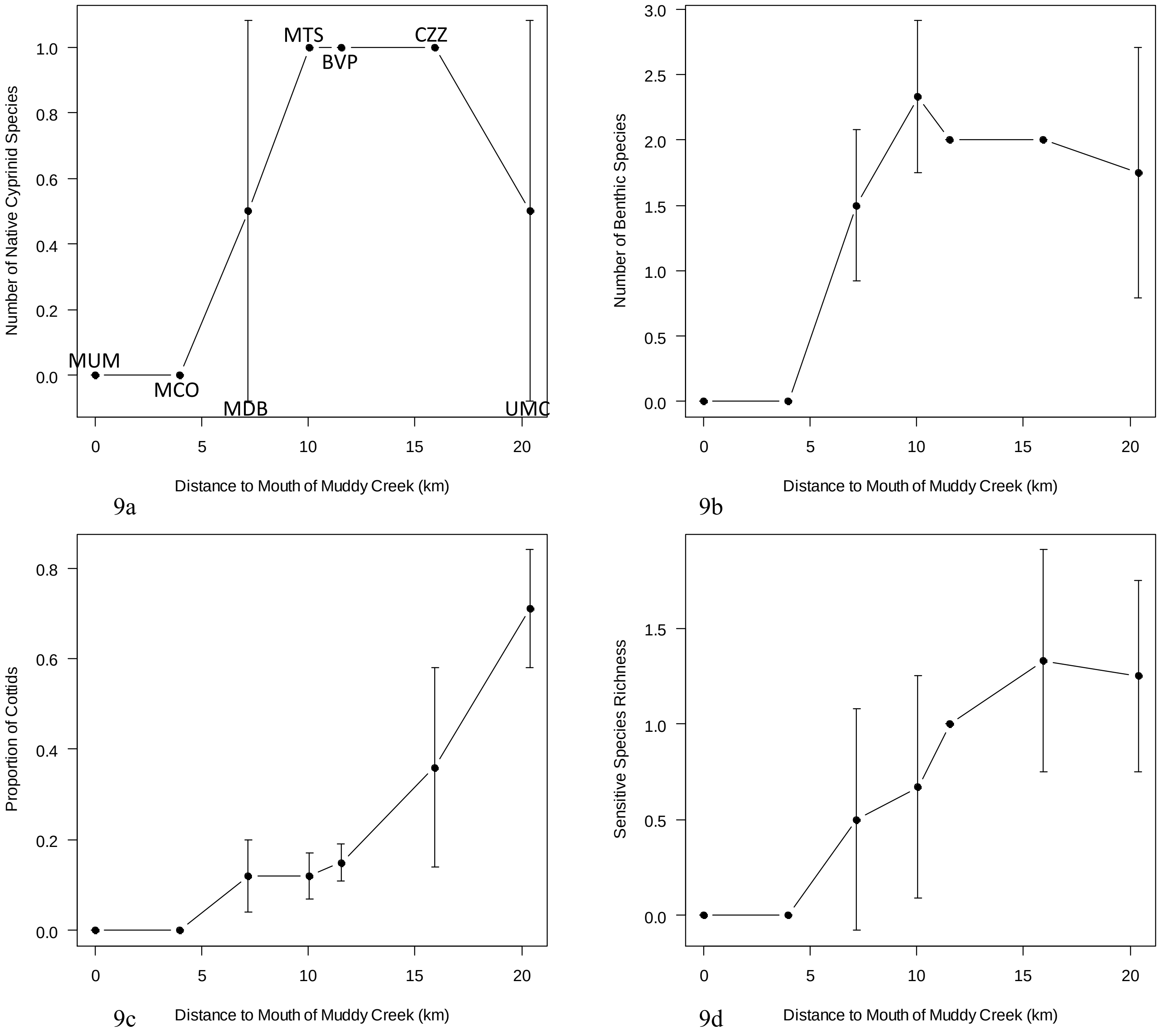
8a

8b

8c

8d

Figure 8a-d. The number of genera that belong to the macroinvertebrate order Ephemeroptera (a), the number of genera that belong to the macroinvertebrate order Plecoptera (b), the total number of macroinvertebrate genera present in the benthic community (c), and the Genus Level Index of Most Probable Stream Status (GLIMPSS) scores (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2006-2011 and 2013-2014 data. Data from 2012 is pulled out due to AMD-treatment occurring during this sampling period on Fickey Run. The horizontal line in Figure d represents the impairment threshold for GLIMPSS (62.0) as defined by the WVDEP. Site abbreviations as in Table 1.



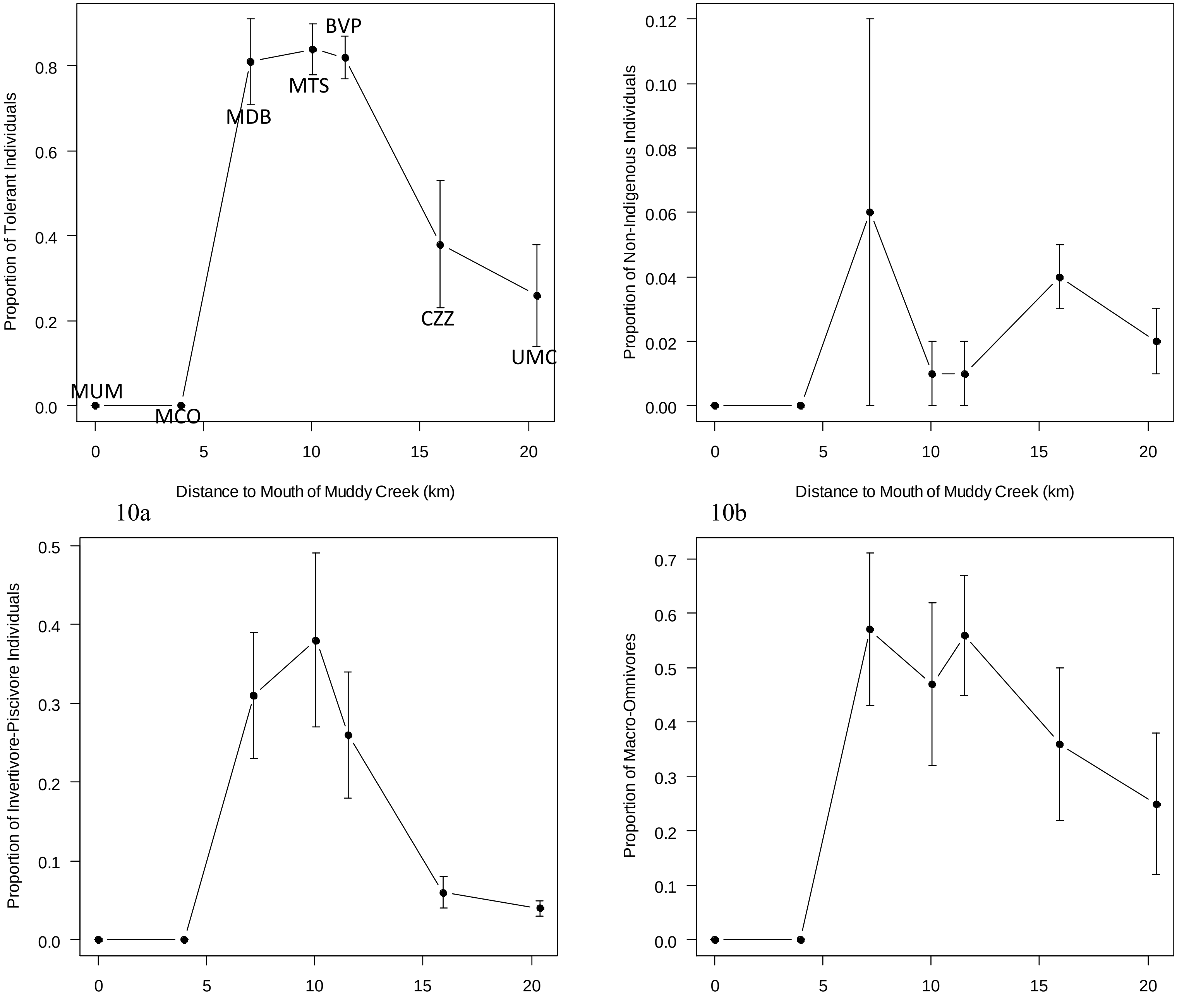
9a

9b

9c

9d

Figure 9a-d. The number of native Cyprind species (a), number of benthic fish species (b), proportion of Cottids (c), and sensitive fish species richness (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2002, 2008, 2013, and 2014 data. Site abbreviations as in Table 1.



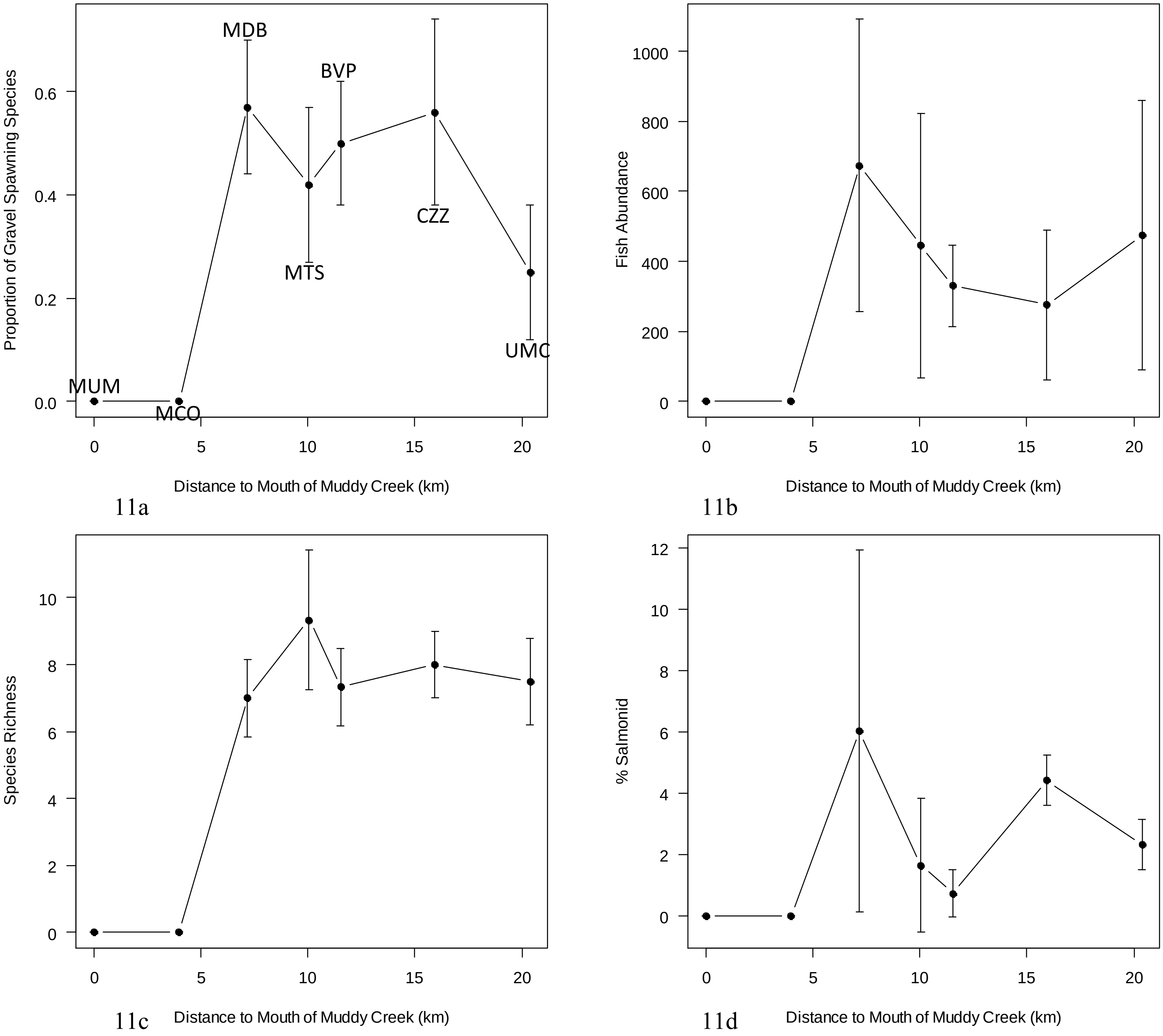
10a

10b

10c

10d

Figure 10a-d. The proportion of tolerant fish (a), non-indigenous fish (b), invertivore-piscivores (c), and macro-omnivores (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2002, 2008, 2013, and 2014 data. Site abbreviations as in Table 1.



11a

11b

11c

11d

Figure 11a-d. Proportion of gravel spawning fish species (a), fish abundance (b), the total number of fish species present in the assemblage (c), and percent of the fish community comprised of trout (d) along the Muddy Creek stream continuum. Error bars represent standard deviation about the long-term mean for 2002, 2008, 2013, and 2014 data. Site abbreviations as in Table 1.

Table 1. Site names, abbreviations, GPS coordinates of sampling locations, and the stream kilometer for each site along the Muddy Creek mainstem (for reference to Figures 5 – 11).

Site Name	Site Abbrev	Latitude	Longitude	Stream Kilometer
Muddy Creek at Mouth	MUM	39.51217	79.64681	0.0
Muddy Creek above Crab Orchard Run	MCO	39.54025	79.63189	4.0
Muddy Creek at Million Dollar Bridge	MDB	39.56149	79.62199	7.2
Muddy Creek at Tack Shop	MTS	39.57969	79.60688	10.1
Muddy Creek at Brandonville Pike	BVP	39.58860	79.59847	11.5
Muddy Creek at Cuzzart	CZZ	39.58509	79.56506	15.9
Upper Muddy Creek	UMC	39.57237	79.53014	20.4

Table 2. Means and standard deviations of water chemistry parameters for 2006 – 2014 data at sites sampled along the Muddy Creek stream continuum. Data from 2012 are pulled out due to AMD-treatment occurring during this sampling period on Fickey Run. Means are reported in mg/L. Conductivity is reported in µS/cm; alkalinity and acidity is reported in mg/L $CaCO_3$ equivalents; Q is reported in gallons per minute.

	Sites													
	Muddy Creek at Mouth		Muddy above Crab Orchard		Muddy at Million Dollar Bridge		Muddy at Tack Shop		Muddy at Brandonville Pike		Muddy Creek at Cuzzart		Upper Muddy Creek	
	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012
pH	5.27 (1.03)	6.52	4.24 (0.64)	4.95	7.12 (0.51)	7.01	7.07 (0.34)	7.12	6.26 (0.11)	NA	6.98 (0.57)	6.99	7.33 (0.63)	7.16
Conductivity	564.11 (117.82)	443.00	592.11 (143.56)	467.00	211.78 (30.85)	183.00	193.67 (80.19)	142.00	110.50 (10.61)	NA	68.33 (6.12)	71.00	106.00 (11.53)	99.00
TDS	0.37 (0.08)	0.29	0.38 (0.09)	0.30	0.14 (0.02)	0.12	0.13 (0.05)	0.09	0.07 (0.01)	NA	0.04 (0.00)	0.05	0.07 (0.01)	0.07
TSS	34.78 (21.42)	40.00	21.33 (8.83)	30.00	5.60 (5.40)	1.19	10.24 (18.85)	4.00	6.00 (0.00)	NA	3.42 (4.29)	1.19	5.63 (5.51)	1.19
Alkalinity	3.06 (3.62)	7.65	1.81 (3.43)	4.80	28.42 (5.01)	30.67	22.77 (12.63)	20.93	17.27 (3.17)	NA	18.85 (4.46)	22.00	31.05 (7.34)	33.50
Acidity	83.52 (52.39)	29.86	86.39 (58.50)	45.18	21.81 (38.97)	10.96	19.11 (31.40)	8.74	8.29 (5.96)	NA	15.59 (34.75)	4.91	1.06 (2.15)	0.50
Al	2.44 (1.84)	0.05	4.04 (2.05)	0.87	0.05 (0.03)	0.05	0.07 (0.06)	0.05	0.05 (0.05)	NA	0.16 (0.21)	0.05	0.20 (0.30)	0.05

Fe	2.55 (1.50)	1.67	3.06 (1.46)	2.42	0.03 (0.02)	0.05	0.14 (0.27)	0.05	0.03 (0.02)	NA	0.10 (0.15)	0.05	0.12 (0.19)	0.05
Mn	0.86 (0.53)	0.52	1.17 (0.37)	0.62	0.23 (0.27)	0.05	0.17 (0.04)	0.05	0.12 (0.02)	NA	0.09 (0.09)	0.05	0.03 (0.03)	0.05
SO_4	240.10 (59.45)	128.00	243.50 (67.72)	160.00	53.94 (21.79)	35.50	55.18 (24.26)	26.60	30.75 (6.86)	NA	41.76 (60.87)	13.20	11.61 (2.85)	13.10
Ba	0.06 (0.05)	0.08	0.05 (0.04)	0.06	0.13 (0.12)	0.07	0.04 (0.03)	0.08	0.08 (0.06)	NA	0.10 (0.06)	0.08	0.11 (0.15)	0.08
Cu	0.01 (0.01)	0.01	0.01 (0.01)	0.01	0.01 (0.00)	0.01	0.01 (0.00)	0.01	0.02 (0.01)	NA	0.04 (0.07)	0.01	0.01 (0.01)	0.01
Cl	2.51 (0.51)	1.88	2.53 (0.51)	1.83	2.03 (0.63)	1.37	1.62 (0.27)	1.36	1.31 (0.03)	NA	1.28 (0.19)	1.09	1.75 (0.33)	1.69
Co	0.04 (0.02)	0.02	0.04 (0.02)	0.02	0.01 (0.01)	0.01	0.01 (0.01)	0.01	0.01 (0.00)	NA	0.05 (0.07)	0.01	0.01 (0.01)	0.01
Ca	47.33 (13.81)	40.23	46.46 (14.07)	40.18	21.59 (6.50)	18.56	19.73 (11.95)	13.53	11.59 (2.30)	NA	7.61 (2.04)	8.24	21.05 (21.05)	12.41
Cd	0.01 (0.00)	0.01	0.01 (0.00)	0.01	0.01 (0.00)	0.01	0.01 (0.00)	0.01	0.01 (0.00)	NA	0.04 (0.06)	0.01	0.01 (0.00)	0.01
Se	0.04 (0.02)	0.02	0.05 (0.07)	0.20	0.07 (0.07)	0.02	0.04 (0.03)	0.02	0.03 (0.01)	NA	0.08 (0.10)	0.06	0.05 (0.06)	0.02
Mg	16.44 (4.01)	12.52	16.39 (4.31)	13.45	7.24 (2.09)	5.85	6.56 (4.34)	3.99	3.35 (0.45)	NA	1.41 (0.94)	1.09	4.32 (6.23)	1.38

Na	4.64 (3.09)	3.45	4.83 (4.81)	2.79	3.10 (2.45)	1.02	2.94 (2.79)	1.35	1.27 (0.37)	NA	2.45 (2.47)	1.24	2.33 (2.14)	1.72
Ni	0.06 (0.02)	0.03	0.09 (0.06)	0.03	0.02 (0.03)	0.01	0.01 (0.00)	0.01	0.01 (0.00)	NA	0.05 (0.10)	0.01	0.01 (0.01)	0.01
Zn	0.20 (0.13)	0.15	0.19 (0.11)	0.11	0.08 (0.09)	0.06	0.02 (0.01)	0.06	0.08 (0.07)	NA	0.06 (0.07)	0.06	0.06 (0.09)	0.06
Q	2.28 (1.29)	NA	1.67 (1.10)	NA	1.43 (0.97)	NA	1.08 (0.93)	NA	0.60 (0.16)	NA	1.03 (0.64)	NA	0.42 (0.16)	NA

Table 3. Means and standard deviations of benthic macroinvertebrate community metrics and indexes of biotic integrity for 2006 – 2014 data at sites sampled along the Muddy Creek stream continuum. Data from 2012 are pulled out due to AMD-treatment occurring during this sampling period on Fickey Run.

	Sites													
	Muddy Creek at Mouth		Muddy above Crab Orchard		Muddy at Million Dollar Bridge		Muddy at Tack Shop		Muddy at Brandonville Pike		Muddy at Cuzzart		Upper Muddy Creek	
	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012	Mean (SD)	2012
GLIMPSS	15.19 (14.04)	26.53	16.68 (11.61)	11.48	64.25 (17.29)	78.61	63.64 (18.87)	78.68	60.53 (12.45)	NA	79.91 (12.21)	92.10	87.96 (6.57)	91.48
E Genus Richness	2.00 (2.00)	1.00	1.11 (1.05)	0.00	5.25 (2.43)	7.00	5.78 (2.86)	7.00	5.00 (0.00)	NA	7.56 (1.67)	9.00	10.14 (3.39)	13.00
P Genus Richness	2.33 (3.08)	1.00	0.89 (0.60)	1.00	4.25 (1.04)	5.00	4.44 (1.51)	5.00	5.00 (1.41)	NA	5.44 (2.88)	7.00	5.86 (1.57)	6.00
Genus Richness	11.11 (11.04)	6.00	6.78 (4.89)	8.00	24.50 (6.09)	30.00	24.33 (8.08)	28.00	25.50 (6.36)	NA	35.22 (12.92)	38.00	40.71 (10.86)	50.00
% EPT Families	24.64 (22.27)	33.33	24.34 (30.36)	4.48	64.76 (15.59)	79.56	62.02 (15.60)	75.68	53.81 (0.68)	NA	59.74 (14.79)	70.35	67.47 (9.44)	60.89
% 2 Dominant	73.33 (17.98)	77.78	81.81 (15.30)	80.27	53.53 (14.50)	72.33	49.89 (13.90)	53.55	46.79 (16.67)	NA	46.81 (10.12)	53.33	40.24 (5.74)	43.72
WVSCI	44.28 (19.95)	39.26	35.91 (18.88)	32.81	78.61 (14.75)	89.58	77.35 (14.03)	88.13	77.01 (13.22)	NA	82.53 (10.04)	91.21	90.51 (3.17)	90.34

% E	9.76 (12.43)	31.48	4.53 (5.13)	0.00	40.06 (20.51)	67.51	27.48 (15.29)	53.01	23.65 (1.12)	NA	36.50 (14.62)	55.77	39.70 (11.78)	26.00
EPT Family Richness	4.44 (4.48)	2.00	2.89 (2.03)	2.00	10.50 (2.98)	12.00	10.89 (3.48)	13.00	11.00 (1.41)	NA	14.33 (4.18)	17.00	17.00 (3.56)	18.00
Family Richness	9.67 (7.71)	7.00	6.44 (4.53)	8.00	17.88 (3.04)	20.00	17.89 (4.46)	20.00	19.00 (5.66)	NA	22.44 (7.40)	27.00	29.00 (6.19)	33.00

Table 4. Means and standard deviations of fish community metrics for 2002, 2008, 2013, and 2014 data at sites sampled along the Muddy Creek stream continuum.

	Sites													
	Muddy at Mouth		Muddy above Crab Orchard		Million Dollar Bridge		Muddy at Tack Shop		Muddy at Brandonville Pike		Muddy at Cuzzart		Upper Muddy Creek	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
# of Native Cyprinid Species	0.00	0.00	0.00	0.00	0.50	0.58	1.00	0.00	1.00	0.00	1.00	0.00	0.50	0.58
# of Benthic Species	0.00	0.00	0.00	0.00	1.50	0.58	2.33	0.58	2.00	0.00	2.00	0.00	1.75	0.96
Proportion of Cottids	0.00	0.00	0.00	0.00	0.12	0.08	0.12	0.05	0.15	0.04	0.36	0.22	0.71	0.13
Sensitive Species Richness	0.00	0.00	0.00	0.00	0.50	0.58	0.67	0.58	1.00	0.00	1.33	0.58	1.25	0.50
Proportion of Tolerant Individuals	0.00	0.00	0.00	0.00	0.81	0.10	0.84	0.06	0.82	0.05	0.38	0.15	0.26	0.12
Proportion of Non-Indigenous Individuals	0.00	0.00	0.00	0.00	0.06	0.06	0.01	0.01	0.01	0.01	0.04	0.01	0.02	0.01

Proportion of Invertivore-Piscivore Individuals	0.00	0.00	0.00	0.00	0.31	0.08	0.38	0.11	0.26	0.08	0.06	0.02	0.04	0.01
Proportion of Macro-Omnivores	0.00	0.00	0.00	0.00	0.57	0.14	0.47	0.15	0.56	0.11	0.36	0.14	0.25	0.13
Proportion of Gravel Spawning Species	0.00	0.00	0.00	0.00	0.57	0.13	0.42	0.15	0.50	0.12	0.56	0.18	0.25	0.13
Abundance	0.00	0.00	0.00	0.00	674.00	417.01	445.67	378.00	330.00	115.86	276.00	214.08	475.00	384.72
Species Richness	0.00	0.00	0.00	0.00	7.00	1.15	9.33	2.08	7.33	1.15	8.00	1.00	7.50	1.29
% Salmonid	0.00	0.00	0.00	0.00	6.01	5.90	1.64	2.19	0.72	0.76	4.40	0.82	2.31	0.81

Table 5. Means and standard deviations of physical habitat parameters (RVHA) for 2008, 2013, and 2014 data at sites sampled along the Muddy Creek stream continuum. The RVHA score is reported in percentage of total in the last line of the table.

	Sites													
	Muddy Creek at Mouth		Muddy above Crab Orchard		Muddy at Million Dollar Bridge		Muddy at Tack Shop		Muddy at Brandonville Pike		Muddy at Cuzzart		Upper Muddy Creek	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Epifunal Substrate/available cover	17.00	NA	15.50	2.12	16.33	0.58	17.50	0.71	16.00	1.41	19.50	0.71	18.00	1.00
Embeddedness	10.00	NA	13.50	6.36	17.33	2.52	16.50	0.71	11.50	2.12	14.50	4.95	16.33	0.58
Velocity/Depth Regime	16.00	NA	18.50	0.71	17.00	1.00	15.50	2.12	15.50	2.12	17.00	0.00	16.00	2.65
Sediment Deposition	18.00	NA	18.00	0.00	15.67	1.53	16.50	0.71	11.50	6.36	15.00	2.83	15.00	1.00
Channel Flow Status	17.00	NA	17.50	0.71	17.33	0.58	14.50	2.12	15.50	2.12	15.50	0.71	17.33	2.08
Channel Alteration	19.00	NA	17.00	1.41	13.33	0.58	14.00	1.41	14.50	0.71	16.50	2.12	18.00	1.00
Frequency of Riffles	19.00	NA	18.50	0.71	16.67	1.53	18.00	0.00	15.00	1.41	17.00	1.41	18.67	0.58
Left Bank Stability	9.00	NA	9.00	1.41	7.33	2.31	7.00	0.00	8.00	1.41	9.00	0.00	9.00	1.00
Right Bank Stability	9.00	NA	8.50	0.71	8.67	1.53	7.00	0.00	8.00	1.41	9.00	0.00	8.33	0.58
Left Vegetative Protection	10.00	NA	8.00	2.83	7.00	1.00	8.00	0.00	7.50	0.71	8.50	0.71	10.00	0.00

Right Vegetative Protection	5.00	NA	8.50	2.12	8.67	1.53	8.50	0.71	6.50	0.71	8.50	0.71	9.33	1.15
Left Riparian Vegetative Zone Width	10.00	NA	10.00	0.00	3.33	0.58	8.00	1.41	7.00	1.41	7.50	0.71	10.00	0.00
Right Riparian Vegetative Zone Width	3.00	NA	4.00	1.41	7.67	2.52	7.00	2.83	4.50	2.12	7.50	0.71	9.67	0.58
RVHA total (%)	81.00	NA	83.25	6.01	78.17	1.26	79.00	4.95	70.50	11.31	82.50	3.54	87.83	2.93

Appendix 1. List of some of the important scientific publications and theses (i.e., manuscripts to be submitted for publication) that have come from the sampling of the Muddy Creek watershed. These have included sampling of the larger Cheat River watershed as well.

Carlson, B. 2013. Water chemistry and benthic macroinvertebrate community stability along an acid mine drainage (AMD) impairment gradient, and response to AMD treatment within a HUC-12 Appalachian watershed. M.S Thesis. West Virginia University, Morgantown.

Freund, J. G. and J. T. Petty. 2007. Response of fish and macroinvertebrate bioassessment indices to water chemistry in a mined Appalachian watershed. Environmental Management 39:707-720.

Merovich, G. T., Jr. and J. T. Petty. 2007. Interactive effects of multiple stressors and restoration priorities in a mined Appalachian watershed. Hydrobiologia 575:13-31.

Merovich, G. T., Jr. and J. T. Petty. 2010. Continuous response of benthic macroinvertebrate assemblages to a discrete disturbance gradient: consequences for diagnosing stressors. Journal of the North American Benthological Society 29:1241-1257.

Merovich, G. T., Jr., J. T. Petty, M. P. Strager, and J. B. Fulton. 2013. Hierarchical classification of stream condition: a house-neighborhood framework for establishing conservation priorities in complex riverscapes. Freshwater Science 32:874-891.

Merovich, G. T., Jr., J. M. Stiles, J. T. Petty, J. Fulton, and P. F. Ziemkiewicz. 2007. Water chemistry based classification of streams and implications for restoring mined Appalachian watersheds. Environmental Toxicology and Chemistry 26:1361-1369.

Petty, J. T., J. B. Fulton, M. P. Strager, G. T. Merovich, Jr., J. M. Stiles, and P. F. Ziemkiewicz. 2010. Landscape indicators and thresholds of stream ecological impairment in an intensively mined Appalachian watershed. Journal of the North American Benthological Society 29:1292-1309.