ECOLOGICAL ASSESSMENT OF THREE OKLAHOMA STREAMS IMPACTED BY MINE DRAINAGE: HABITAT AND WATER QUALITY[1]

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Abstract: Eastern Oklahoma's water resources are impacted by abandoned mine drainage. Passive treatment strategies have been demonstrated to improve water quality at abandoned mines, but watershed reclamation strategies, including a complete assessment of physical habitat degradation of stream ecosystems, are lacking. Mine drainage impacts to three Oklahoma streams were investigated by analyzing water quality, habitat availability, and riffle substrate distribution. Net acidic mine drainage originating from abandoned underground and surface coal mining activities has impacted Pit Creek (Latimer County) for more than 70 years. Beaver and Tar Creeks (Ottawa County) are impacted by net alkaline mine drainage from abandoned lead and zinc mining activities. Overall impact to water quality and habitat availability was assessed. All streams were determined to be impaired by mine drainage originating from discharges, seeps, and leachate derived from mine waste piles. Stream habitat quality varied considerably based on both mining and non-mining related impacts. As a result of this analysis, watershed reclamation strategies, based on passive treatment system design and implementation, will be prioritized and the potential for stream ecosystem recovery evaluated.

Additional key words: habitat availability, water quality, passive treatment

Introduction

Abandoned mine drainage is an environmental problem affecting eastern Oklahoma's water resources. Mine drainage occurs when water and oxygen contact sulfidic strata exposed during mining operations. Depending on the surrounding mineralogy, oxidation reactions can release sulfuric acid and dissolved metals, e.g., Fe, Al, Mn, Zn, Pb and Cd, into the water column. These potentially toxic materials may flow into surface waters, and result in copious metal precipitation

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[1] Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation and The 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2003 pp 496-511
DOI: 10.21000/JASMR03010496

https://doi.org/10.21000/JASMR03010496

and alterations in the original pH range of the aquatic ecosystem. Active mining operations are required to meet strict effluent guidelines but mines abandoned prior to enactment of reclamation laws may still impact local water bodies.

Mining impacts to stream biota have historically focused on water quality impairments (Winner et al., 1980; Clements et al., 1988; Moore et al., 1991; Clements and Kiffney, 1994; Clements et al., 2000; Besser et al., 2001). Even with water quality improvements, biological recovery can be limited due to the lack of suitable habitat heterogeneity (Iversen et al, 1993; Friberg et al, 1998; Laasonen et al, 1998). Mine wastes and metal precipitates may alter substrate composition, sediment deposition, and the physical character of the stream bed (Scullion and Edwards, 1980; Hellawell, 1986). Metal precipitates can affect a stream, similar to sedimentation, by smothering the bottom and filling crevices that provide available niches for stream life (Scullion and Edwards, 1980; Cherry et al., 2001; Schmidt et al., 2002).

Several studies have used an integrative approach to assess the degree of impact to watersheds receiving mine drainage (e.g., Cherry et al, 2001; Schmidt et al, 2002). The integrative assessments include various combinations of water and sediment chemistry analysis, toxicity tests, benthic macroinvertebrate sampling, and habitat assessments. Habitat assessments commonly use Environmental Protection Agency (U.S. EPA) Rapid Bioassessment Protocols (Plafkin et al, 1989; Barbour et al, 1999). The parameters assessed include bottom substrate/available cover, embeddedness or pool bottom characterization, velocity/depth or pool variability, sediment deposition, channel flow status, channel alteration, frequency of riffles or sinuosity, bank stability, bank vegetation protection, and riparian vegetative zone width. These parameters have been selected due to their overall importance to aquatic life, but may not be sufficient to assess physical impacts associated with mining activities.

Degradation or alteration of the physical habitat can limit the stream biotic community and result in an impairment of the stream ecosystem (Karr, 1991; Karr and Chu, 1999). Therefore, it is important to have a physical assessment approach that includes all parameters associated with the potential habitat impairment. This study investigated the feasibility of using U.S. EPA's Rapid Bioassessment Protocols to assess watersheds impacted by mining activities in eastern Oklahoma. By comparing habitat assessments, substrate analyses of the sampled riffles, and water quality parameters, the degree and type of mining impact to a watershed was determined.

Understanding the character of the mining impact will help prioritize reclamation efforts and the development of treatment strategies.

Methods

Study Sites

Tar Creek and Beaver Creek are located in Ottawa County in northeastern Oklahoma, and are impacted by abandoned lead and zinc mining activities. These watersheds are located within the Tar Creek Superfund site. The composition of the mine drainage impacting these two watersheds is characterized by near-neutral pH, net alkalinity, and elevated dissolved metal concentrations. Tar Creek is also surrounded by mine waste piles. There were four sampling stations in Tar Creek, and five sampling stations in Beaver Creek.

Pit Creek is located in Latimer County in southeastern Oklahoma. Pit Creek receives mine drainage from several abandoned coal mine discharges. The chemistry of the mine drainage is characterized by low pH, low alkalinity, low dissolved oxygen content, high conductivity, and elevated dissolved metal concentrations. Four stations were sampled in the Pit Creek watershed.

Habitat Assessments

A habitat assessment was performed at each sampling station using the approach outlined by the U.S. EPA Rapid Bioassessment Protocols (Barbour et al., 1999). The ten parameters included in the assessment were epifaunal substrate/available cover, pool substrate characterization, pool variability, sediment deposition, channel flow status, channel alteration, channel sinuosity, bank stability, vegetative protection, and riparian zone width. Scoring for each parameter was preset and ranged from 0 to 10 or 0 to 20 (depending on the parameter) for a total score of 200. Higher scores indicate habitat condition closer to reference or un-impacted conditions. Two independent researchers performed habitat assessments at each station for Tar and Beaver Creeks. Three independent researchers preformed habitat assessments at Pit Creek.

Water Quality

Water quality evaluations were performed at each study site by the collection of grab samples for laboratory analysis and in-situ field measurements in spring and summer. Water samples were analyzed for dissolved Fe, Al, Zn, Cd, Mn, Mg, Ca, and Pb, using atomic absorption spectrophotometry and chloride and sulfate analysis using ion chromatography (APHA, 1998). Grab samples for metal analysis were preserved with 2 ml of 12 N hydrochloric acid to pH ≤ 2, and all water samples were stored at 4°C until analysis (APHA, 1988). *In-situ* field measurements included pH, temperature, conductivity, turbidity, dissolved oxygen, and alkalinity (OCC, 2001).

Riffle Substrate Analyses

Size distribution of the riffle habitats at each station was characterized using the "pebble count" method (Wolman, 1954; Rosgen, 1996). One hundred substrate samples were randomly selected, and the intermediate axis of each substrate sample was measured and recorded.

Results

Habitat Assessments

Habitat assessments in Beaver Creek indicated a high quality habitat (Figure 1). The physical impacts from mining activities such as in-stream metal precipitation and mine waste sedimentation did not appear to affect the habitat scores.

The overall quality of Tar Creek habitat was scored as low (Figure 2). Tar Creek is impacted by mine waste and channelization due to mining activities. Mine waste deposition and sedimentation appears to be one of the major environmental problems in the Tar Creek watershed. The stream-bed is composed primarily of mine waste causing unstable conditions in the channel. The riparian zone is also impacted by mine waste that may limit bank stabilization and riparian vegetation growth.

Pit Creek may be characterized as having moderate habitat quality, but the habitat is impacted by agricultural practices and channelization separate from mining operations. The agricultural impacts include grazing, clearing of the riparian zone, and bank erosion. The metal precipitation and mining impacts to Pit Creek may not be adequately represented by the EPA's Rapid Bioassessment Protocols habitat scores as much as the other habitat impacts.

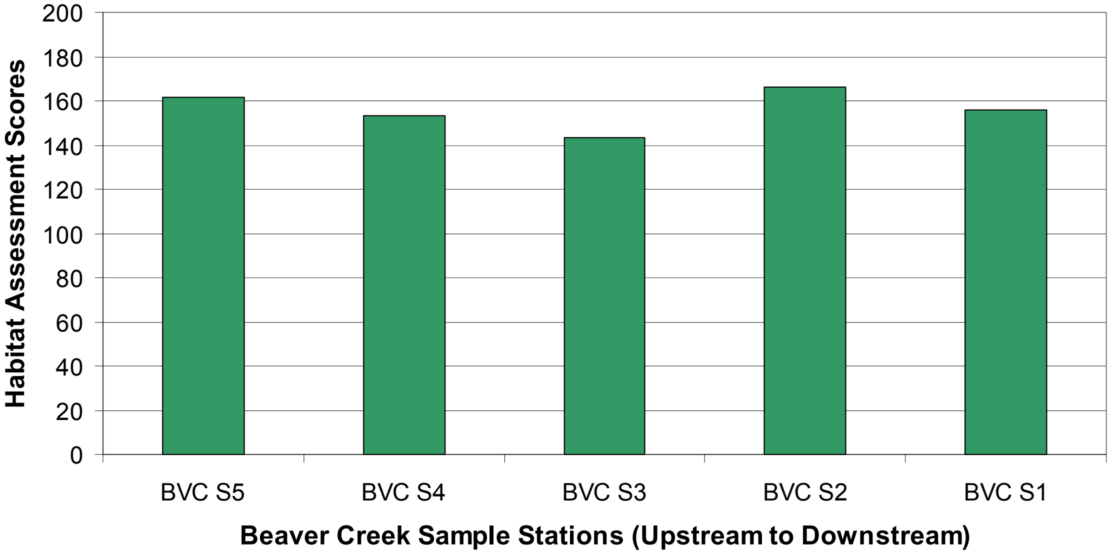

Figure 1: Beaver Creek Habitat Assessment Scores using the U.S. EPA Rapid Bioassessment Protocols (Barbour, 1999).

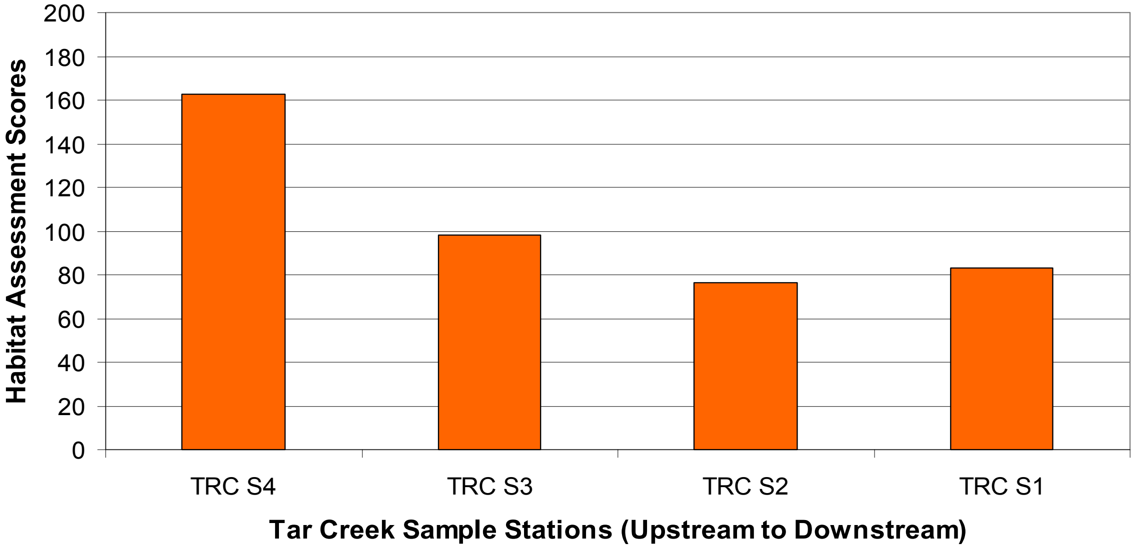

Figure 2: Tar Creek Habitat Assessment Scores using the U.S. EPA Rapid Bioassessment Protocols (Barbour, 1999).

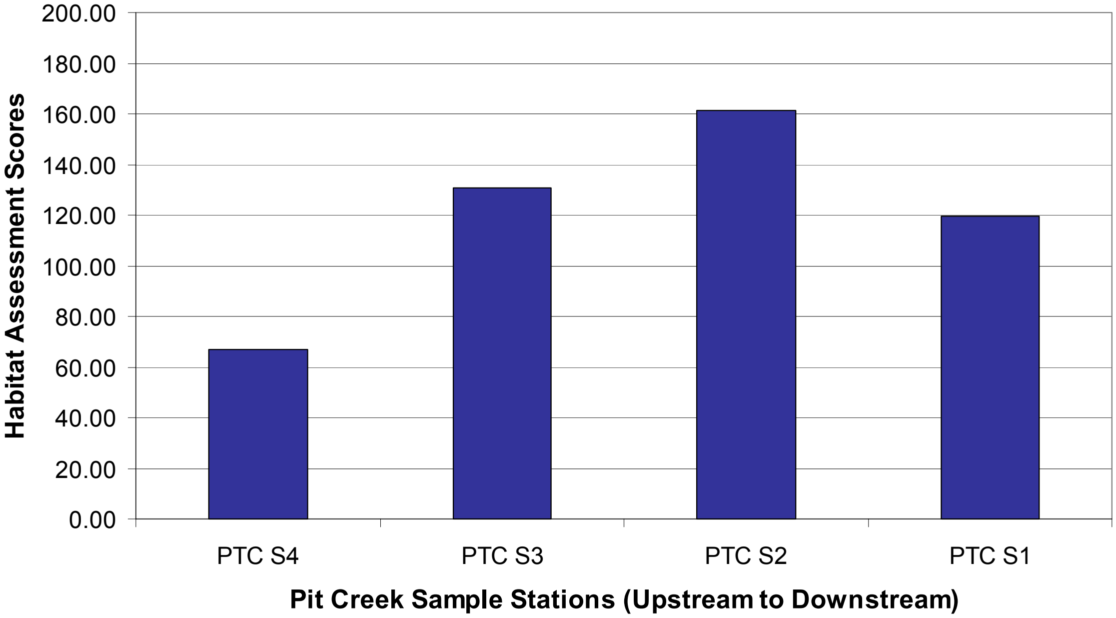

Figure 3: Pit Creek Habitat Assessment Scores using the U.S. EPA Rapid Bioassessment Protocols (Barbour, 1999).

Riffle Substrate Analyses

The substrate size distribution of Beaver Creek's riffle habitats falls primarily in the gravel and cobble ranges (Figure 4). Hard rock mine wastes typically fall in the 2-50 mm size range (Younger et al., 2002). Beaver Creek is minimally impacted by mine waste and the peaks in the gravel range may not be indicative of native substrate. However, mining-derived cobbles may also influence this substrate analysis. Tar Creek is visually impacted by mine waste and this is apparent by the peaks in the lower sized gravel range (Figure 5). Tar Creek sample station 3 is the only station that has a stable riffle habitat and some heterogeneity to the size distribution. Pit Creek also has a heterogeneous size distribution of the riffle substrate (Figure 6) from upstream to downstream sample stations (Pit Creek Station 4 to Station 1). Beaver Creek and Pit Creek both appear to have more heterogeneous distribution of riffle substrates, indicative of a low degree of mine waste impact. Tar Creek's riffle substrate distribution has low heterogeneity and falls primarily in the size range of hard rock mine waste. These data suggests that Tar Creek has a high degree of physical mining impact.

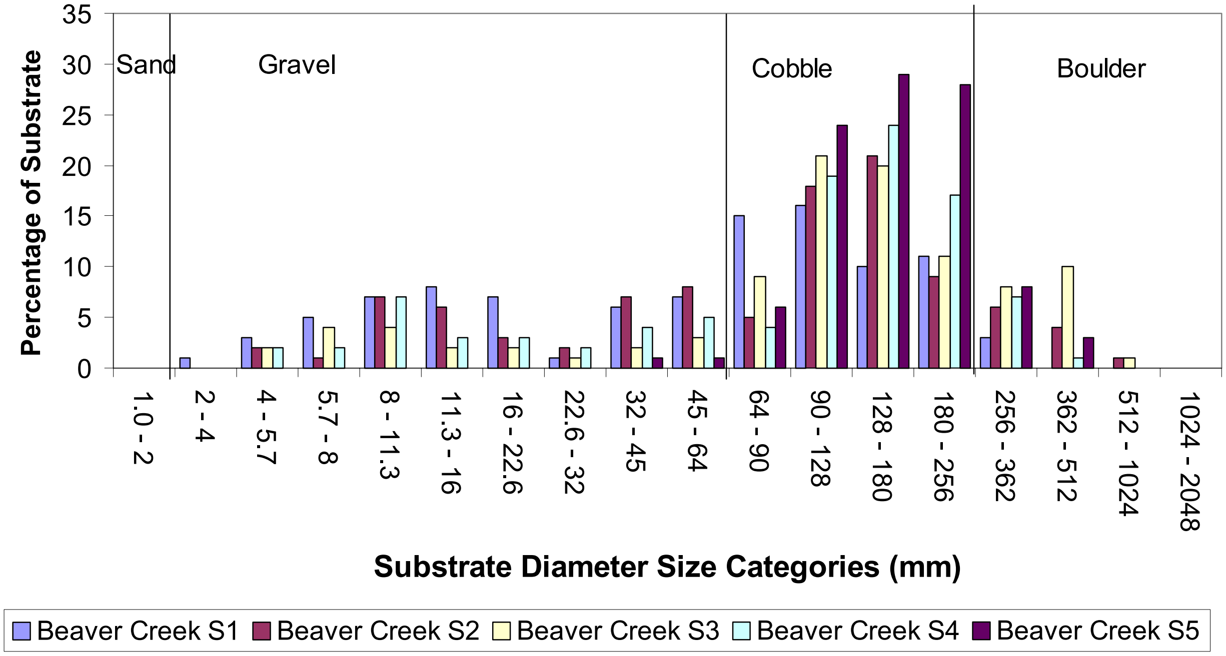

Figure 4: Riffle substrate analysis of Beaver Creek sample stations using the pebble count method (Wolman, 1954; Rosgen, 1996).

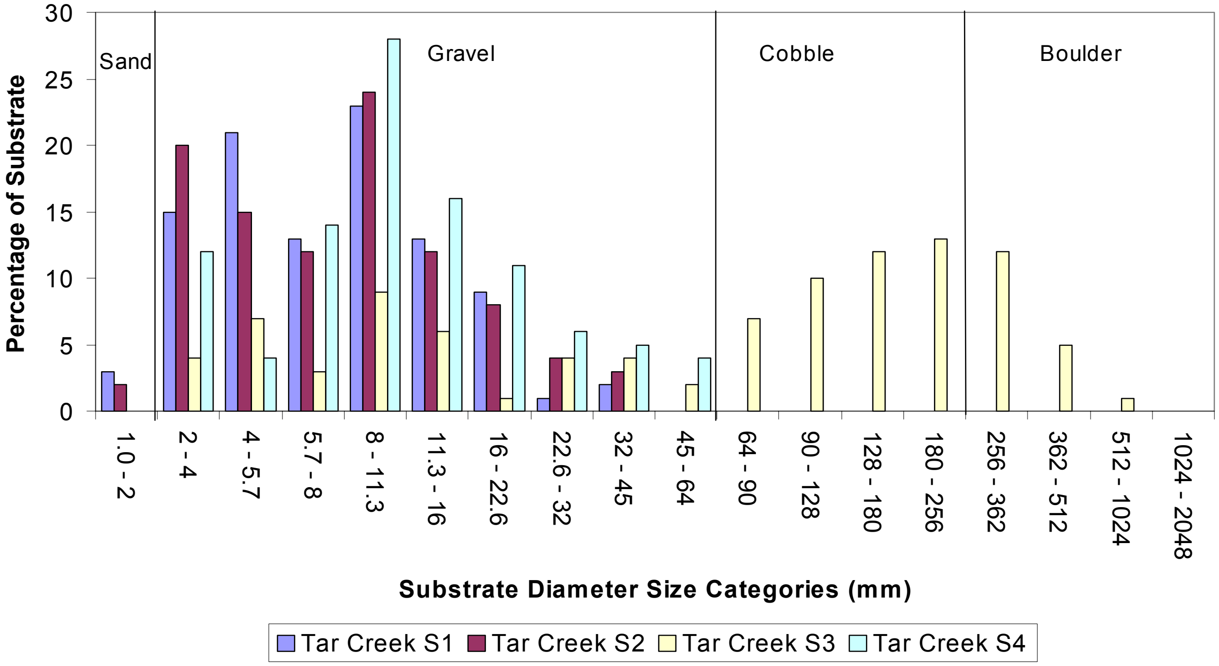

Figure 5: Riffle substrate analysis of Tar Creek sample stations using the pebble count method (Wolman, 1954; Rosgen, 1996).

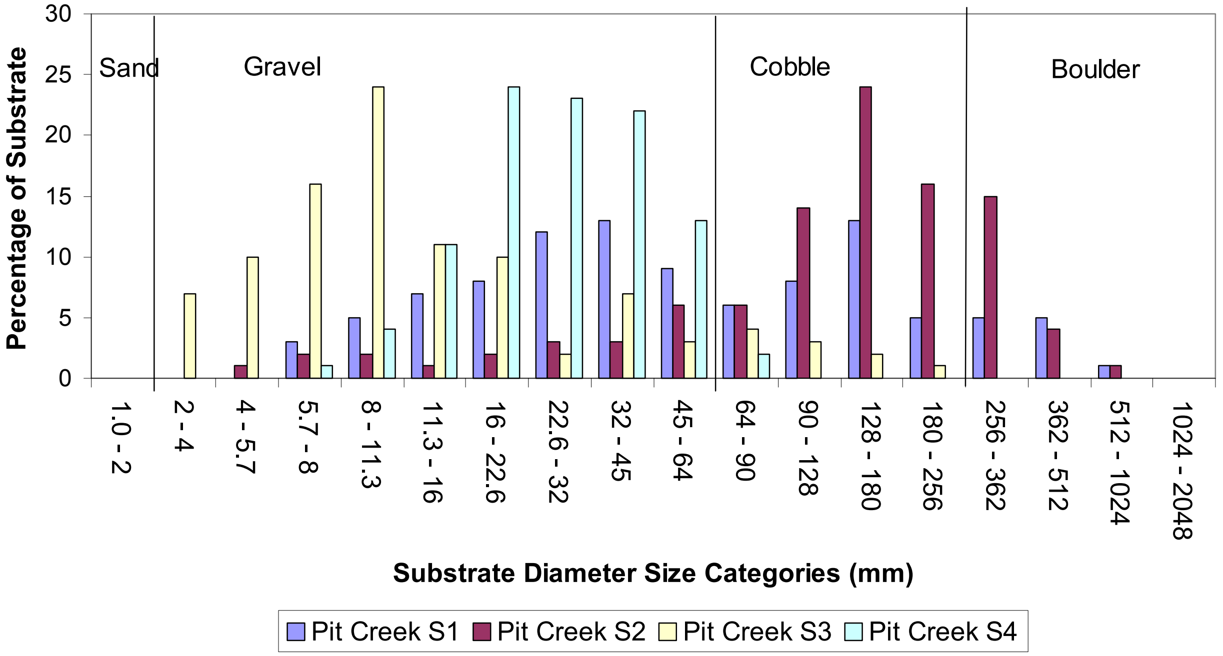

Figure 6: Riffle substrate analysis of Pit Creek sample stations using the pebble count method (Wolman, 1954; Rosgen, 1996).

Water Quality

All three of the studied watersheds are impaired by mine drainage pollution. Beaver Creek has a near neutral pH due to the alkalinity buffering the metal load (Table 1). Mine drainage enters Beaver near its headwaters upstream of sample station 4. Iron concentrations pose a water quality problem and a habitat issue (Figure 6) because precipitated iron hydroxides can impair habitat availability, limiting aquatic communities (Cherry et al., 2002).

Tar Creek also has a near neutral pH, but has a higher metal load (Table 2). Zinc, manganese, and iron (Figure 7) concentrations are much higher than in Beaver Creek. Therefore, Tar Creek has a higher degree of water quality impact and metal precipitation may impact habitat more so than in Beaver Creek. Mine drainage enters Tar Creek downstream of sample station 3, but mine waste piles surround all four sample stations. Total metal concentrations upstream of sample station 3 indicate possible mine waste leachate pollution.

Table 1: Summary of water quality at the sample stations in Beaver Creek. S5 is near the headwaters and station numbers decrease downstream.

	Beaver Creek Sample Stations				
Water Quality Parameters	S5	S4	S3	S2	S1
pH*	8.05 +/- 0.28	7.36 +/- 0.22	7.27 +/- 0.06	7.96 +/- 0.10	7.92 +/- 0.26
Conductivity* (µS/cm)	508.33 +/- 49.52	696.33 +/- 43.82	754.33 +/- 28.36	606.00 +/- 27.78	604.67 +/- 28.36
Alkalinity* (mg/L as CaCO3)	154.17 +/- 30.75	183.17 +/- 8.33	181.33 +/- 1.89	175.83 +/- 10.00	170.56 +/- 9.32
Dissolved Oxygen* (mg/L)	11.21 +/- 2.31	10.08 +/- 1.69	9.59 +/- 1.37	11.65 +/- 2.78	11.46 +/- 3.21
Temperature* (°C)	15.19 +/- 5.78	17.21 +/- 5.50	17.20 +/- 3.23	15.94 +/- 6.48	18.73 +/- 10.87
Turbidity* (NTU)	12.00 +/- 2.26	10.66 +/- 2.49	11.97 +/- 1.24	2.41 +/- 1.46	2.10 +/- 1.26
Zn^{Ψ} (mg/L)	0.25	1.9	1.54	0.38	0.34
Mn^{Ψ} (mg/L)	0.09	0.22	0.26	0.09	0.08

* n = 3, water quality parameter values presented as averages and standard deviations

$^{\Psi}$ n = 2, water quality parameter values presented as averages

Pit Creek may have the highest degree of water quality impact from mine drainage (Table 3, Figure 8). Mine drainage enters this stream near its headwaters. Pit Creek has an acidic pH, and an elevated high metal load. Pit Creek has the highest iron concentration found in any of the studied watersheds. Pit Creek also appears to have the highest degree of water quality impact, and the effects of metal precipitation on habitat are considerable.

Table 2: Summary of water quality at the sample stations in Tar Creek, upstream to downstream.

	Tar Creek Sample Stations			
Water Quality Parameters	S4	S3	S2	S1
pH*	7.29 +/- 0.44	7.06 +/- 0.65	6.30 +/- 0.31	6.30 +/- 0.28
Conductivity* (µS/cm)	979.00 +/- 348.28	1207.33 +/- 355.85	1830.33 +/- 279.11	1848.00 +/- 282.92
Alkalinity* (mg/L as CaCO3)	121.00 +/- 44.86	109.83 +/- 18.28	110.17 +/- 15.33	107.50 +/- 11.76
Dissolved Oxygen* (mg/L)	9.09 +/- 1.52	9.74 +/- 1.38	6.11 +/- 1.95	5.90 +/- 1.21
Temperature* (°C)	20.23 +/- 6.75	21.94 +/- 7.51	17.40 +/- 4.35	17.66 +/- 3.56
Turbidity* (NTU)	3.91 +/- 2.41	6.50 +/- 0.86	17.46 +/- 1.50	23.58 +/- 8.71
Zn^{Ψ} (mg/L)	2.46	5.40	7.10	6.90
Mn^{Ψ} (mg/L)	0.51	1.16	1.23	1.29

* n = 3, water quality parameter values presented as averages and standard deviations

$^{\Psi}$ n = 2, water quality parameter values presented as averages

Table 3: Summary of water quality at the sample stations in Pit Creek, upstream to downstream.

	Pit Creek Sample Stations			
Water Quality Parameters	S4	S3	S2	S1
pH*	2.73 +/- 0.22	2.73 +/- 0.15	3.27 +/- 0.33	5.14 +/- 1.57
Conductivity* (µS/cm)	1926.33 +/- 109.05	1705.33 +/- 497.38	1117.67 +/- 419.47	773.67 +/- 464.55
Alkalinity* (mg/L as CaCO3)	14.28 +/- 24.73	0.00 +/- 0.00	0.00 +/- 0.00	0.00 +/- 0.00
Dissolved Oxygen* (mg/L)	7.60 +/- 2.22	5.59 +/- 1.49	3.73 +/- 1.85	6.21 +/- 0.47
Temperature* (°C)	20.24 +/- 5.50	19.90 +/- 6.68	19.56 +/- 5.31	18.22 +/- 8.42
Turbidity* (NTU)	5.20 +/- 2.97	2.74 +/- 0.70	15.00 +/- 13.06	2.74 +/- 0.61
Zn$^{\Psi}$ (mg/L)	1.09	0.74	0.425	0.33
Mn$^{\Psi}$ (mg/L)	12.55	10.65	7.16	5.62

* n = 3, water quality parameter values presented as averages and standard deviations

$^{\Psi}$ n = 2, water quality parameter values presented as averages

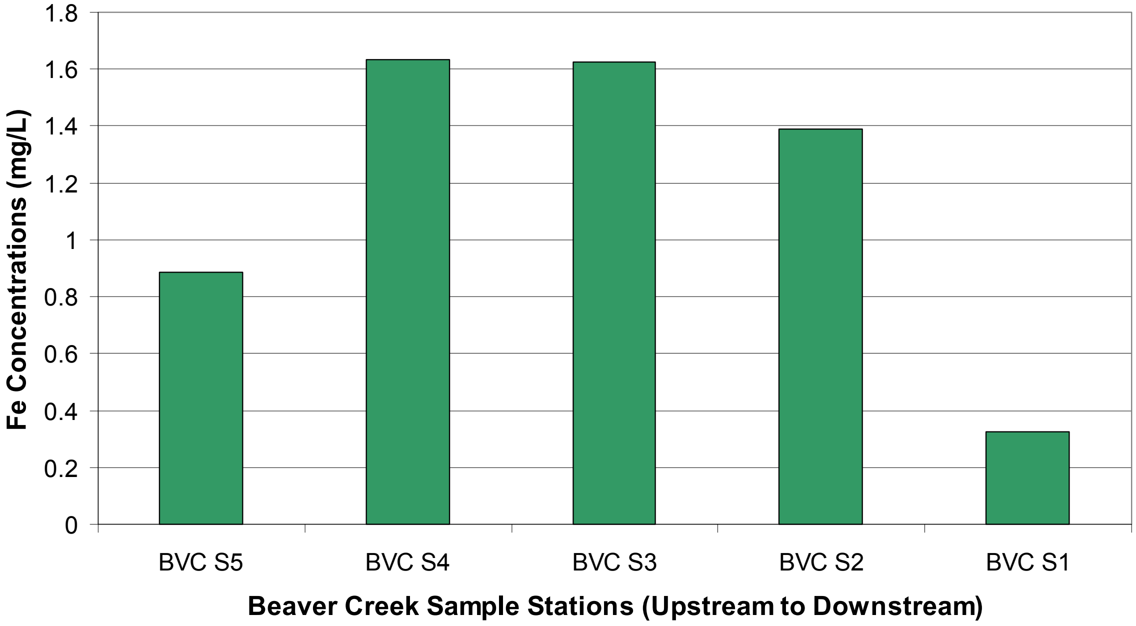

Figure 6: In-stream Fe concentrations (mg/L) in Beaver Creek.

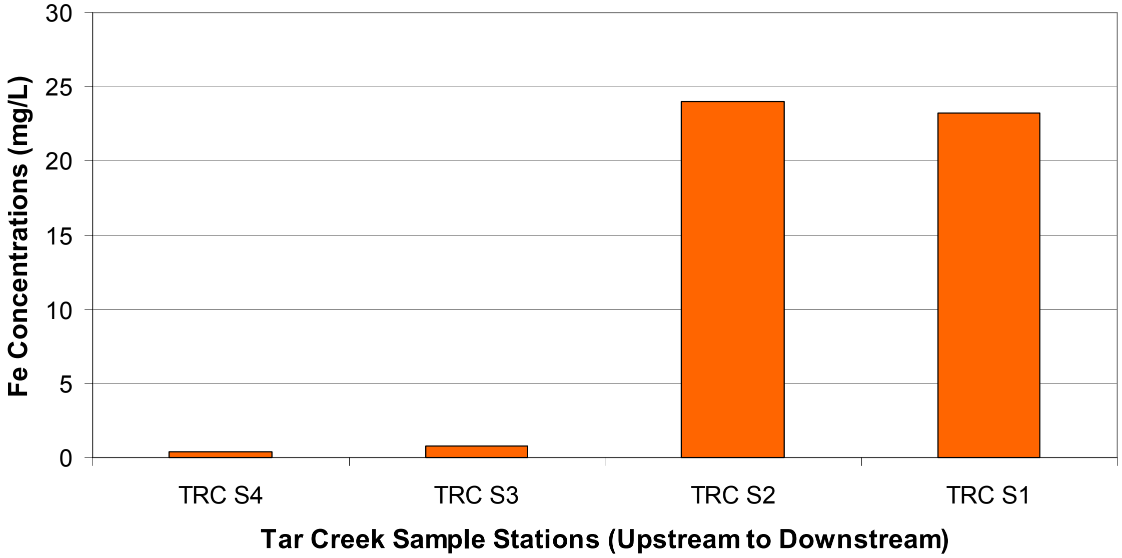

Figure 7: In-stream Fe concentrations (mg/L) in Tar Creek.

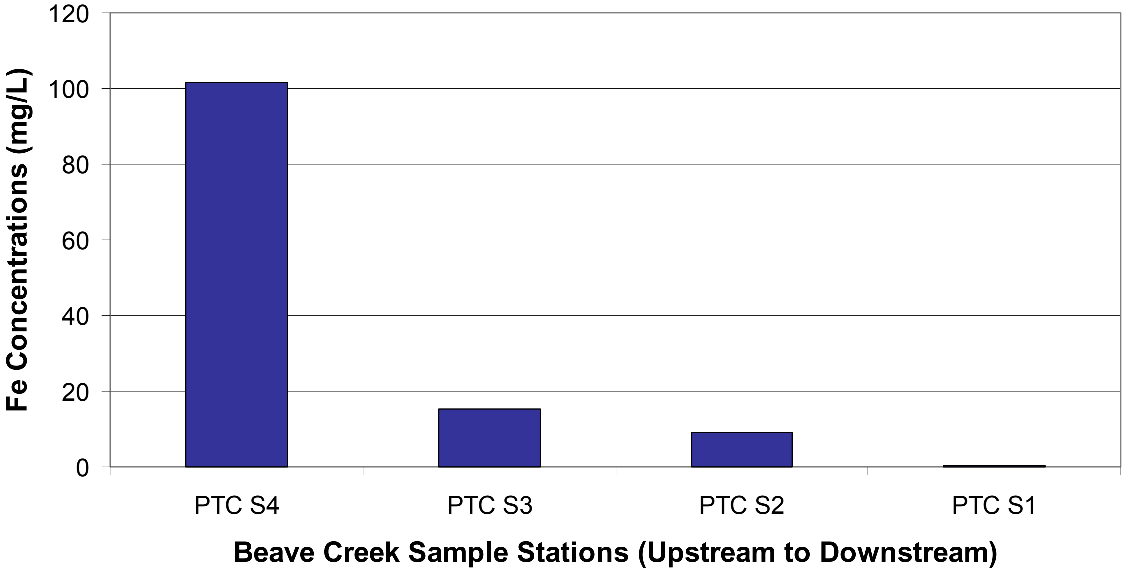

Figure 8: In-stream Fe concentrations (mg/L) in Pit Creek.

Discussion

By comparing the habitat scores, riffle substrate distributions, and in-stream iron concentrations, some insight into the nature and degree of mining impact may be determined. Historic mining activities in the Beaver Creek watershed do not appear to be severely impacting stream habitat scores. The high scores indicate that the impact to Beaver Creek is predominantly a water quality issue. Therefore, the potential for successful reclamation should be high after implementing effective water quality treatment options. There appears to be a minimal impact from mine waste in this stream. However, given the fact that the impact from mine waste is uncertain, water quality and biomonitoring for successful recovery would be necessary after treatment is implemented.

Mining impacts to Tar Creek involves not only water pollution problems, but also severe habitat impacts. Mine waste piles surround Tar Creek. Mine wastes have also washed into the stream, and have completely smothered the stream bottom. The stream-bed is unstable due to the constant movement of the mine waste within the stream. Treatment options for Tar Creek should include water quality improvements and an extensive habitat restoration plan. The habitat restoration plan for this stream should include methods to improve stream bank and bed stability, riparian vegetation, riffle/pool sequence, and stream meanders.

Pit Creek experiences a severe water quality impact from mine drainage and a moderate habitat impact from removal of riparian vegetation. The immediate need to be addressed in Pit Creek is water quality improvement. Pit Creek has an acidic pH and carries an elevated metal load. However, the habitat and riffle substrate distribution would appear to support a diversity of aquatic life if the water quality can be sufficiently improved.

The impact to the physical habitat of streams from mining activities can be analyzed by combining habitat assessments, stream substrate analyses, and dissolved metals. A complete assessment would need to include the impact from metal precipitates, increased flow from discharges, and biological evaluations. Analyzing for metals, such as Fe, does not entirely describe the degree of impact from metal precipitation. Habitat assessments could be modified to include additional parameters such as presence and percent coverage of metal precipitates on stream-beds, presence and percent coverage of mine wastes in stream substrate, and changes in flow regime from mine discharges.

Integrative assessments are needed to determine the overall degree and nature of mining impacts and should include water quality monitoring, habitat assessments, stream-bed substrate analyses, and biomonitoring. Although the impact to the physical habitat was the focus of this study, biomonitoring is also an important component for integrative assessment. Biomonitoring is needed to determine the impact to aquatic life and to create a baseline for potential recovery of the stream ecosystem. Comparing the impact to each component of the integrative assessment may help to prioritize and develop successful treatment strategies.

Acknowledgements

I would like to acknowledge and thank Dr. Keith Strevett, Jennifer Coffey, Denae Athay, Ashling O'Sullivan, and Carrie Evenson for all their valuable help and input.

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