AN EVALUATION OF BENTHIC INVERTEBRATE COMMUNITIES AS AN INDICATOR OF STREAM ECOSYSTEM HEALTH BELOW ACTIVE COAL MINES IN THE ELK RIVER WATERSHED

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ABSTRACT

The objective of this research was to determine whether the benthic invertebrate community structure is impacted by coal mining within the Elk River Basin. Obvious changes in water quality below the coal mines included increased selenium, sulphate, nitrate and nitrite concentrations. Selenium concentration was the only water quality variable that showed a relatively strong negative correlation with changes in benthic community structure, while depth and predominant substrate were also strongly correlated.

Benthic invertebrate tissue samples collected in 2006 and 2007 below Elkview and Coal Mountain Operations suggest that tissue selenium concentration can be within the range of lethal or sublethal toxic effects, therefore affecting community structure. However, benthic invertebrate communities assessed within Michel Creek were found to be within the natural variability as determined by the reference sites sampled, except for a decrease in sensitive species, Ephemeroptera. The abundance and proportion of EPT and Ephemeroptera significantly decreased below coal mining, while Dipterans, particularly Chironomidae, increased. Although the changes within benthic communities were subtle compared to the water quality changes, this does suggest an impact to the aquatic health. In addition, if decreasing Ephemeroptera was truly an effect of coal mining, number of EPT, % EPT, number of Ephemeroptera and % Ephemeroptera may be possible metrics useful for detecting coal mining impacts as suggested by Garcio-Criado et al. (1999).

Key words: macroinvertebrate, Elk Valley, Ephemeroptera, selenium, nitrate, aquatic health

INTRODUCTION

Over the last 30 years, there have been documented water quality changes at the federal/provincial water monitoring station 65 km downstream from the coal mines within the Crowsnest Coalfield at the mouth of the Elk River in southeastern B.C. (Swain, 2007). These changes include orders of magnitude increases in selenium (Se) concentrations (McDonald & Strosher, 1998) and algal growth due to an increase in soluble nitrogen combined with natural phosphorus sources and treated sewage (McDonald, 1987). Water quality within the Elk River has been classified by Environment Canada's water quality index as "marginal" based on increasing levels of selenium, which are currently above the B.C. Aquatic Life Guideline, and increasing levels of nitrate (Environment Canada, 2006).

In response to the discovery of elevated Se in the Elk River in the mid 1990s, the Elk Valley Selenium Task Force, made up of Teck Coal, the B.C. Ministry of Energy, Mines and Petroleum Resources (MEMPR), the B.C. Ministry of Environment (MOE) and Environment Canada (EC), was formed to determine whether the elevated levels in the watershed are causing or could cause an impact on the aquatic environment.

Several studies on fish, birds, waterfowl, and amphibians have been conducted to investigate the potential impacts from selenium arising from coal mining in the Elk Valley (Golder Associates Ltd., 2007); however, potential effects on macroinvertebrate community structure have not been systematically studied.

In 2006, selenium concentrations in benthic invertebrates were between 1.44 mg/kg dw and 10 mg/kg dw in lotic areas and 2.46 mg/kg dw and 30.9 mg/kg dw in lentic areas, within reference and coal mine exposed areas (Minnow Environmental Inc. et al., 2008). These findings were similar to those found by EVS Environment Consultants (2005) in 2001, where selenium concentrations in benthic tissue ranged from 1.5 µg/g dw to 10.2 µg/g dw in lotic areas, within reference and mine exposed areas. A recent review by Debryun and Chapman (2007) discussed selenium toxicity to benthic invertebrates at (internal) concentrations ranging from about 10 to 100 µg Se/g dw where lethality was observed and 1-30 µg Se/g dw where sublethal effects were observed. It is unknown whether the higher levels of selenium in biotic tissue in the Elk Valley are causing toxic effects to specific benthic taxa or causing changes to benthic community structure. Although tissue samples were not taken during this study, selenium concentrations below Elkview Operations at 16.3 & 13.2 µg Se/L, and 3.5 & 1.4 µg Se/L below Coal Mountain Operations (2006 & 2007 respectively) suggest that benthic invertebrate tissues can be within the range of effects and it may be reasonable to expect to see changes within benthic communities below coal mining activity.

Several researchers have shown that benthic community structure does change below coal mines (Bradfield, 1986; Garcia-Criado, Tome, Vega, & Antolin, 1999; MacCausland & McTammany, 2007; Matter and Ney, 1981; Personal Communication C. Podemski, October 6, 2006). A decrease in total abundance and taxa richness have been noted below coal mines causing acid mine drainage (Matter & Ney, 1981). The changes in benthic community structure are often more evident below mines causing acid mine drainage (Bradfield, 1986; Garcia-Criado et al., 1999; MacCausland & McTammany, 2007; Matter and Ney, 1981) in comparison to alkaline coal mines (Chadwick & Canton, 1983), such as those in the Elk Valley, where the changes may be more subtle.

Currently, a summary document evaluating the impacts that coal mining has on the benthic community structure within the Elk River watershed does not exist. This study investigated potential changes to benthic macroinvertebrate community structure below two coal mines that have been operating in one sub-basin of the Elk River for over thirty years.

METHODS

Spatial Aspects of Sampling Strategy

The study sites were located within erosional habitats along Michel Creek, a major tributary to the Elk River (Figure 1).

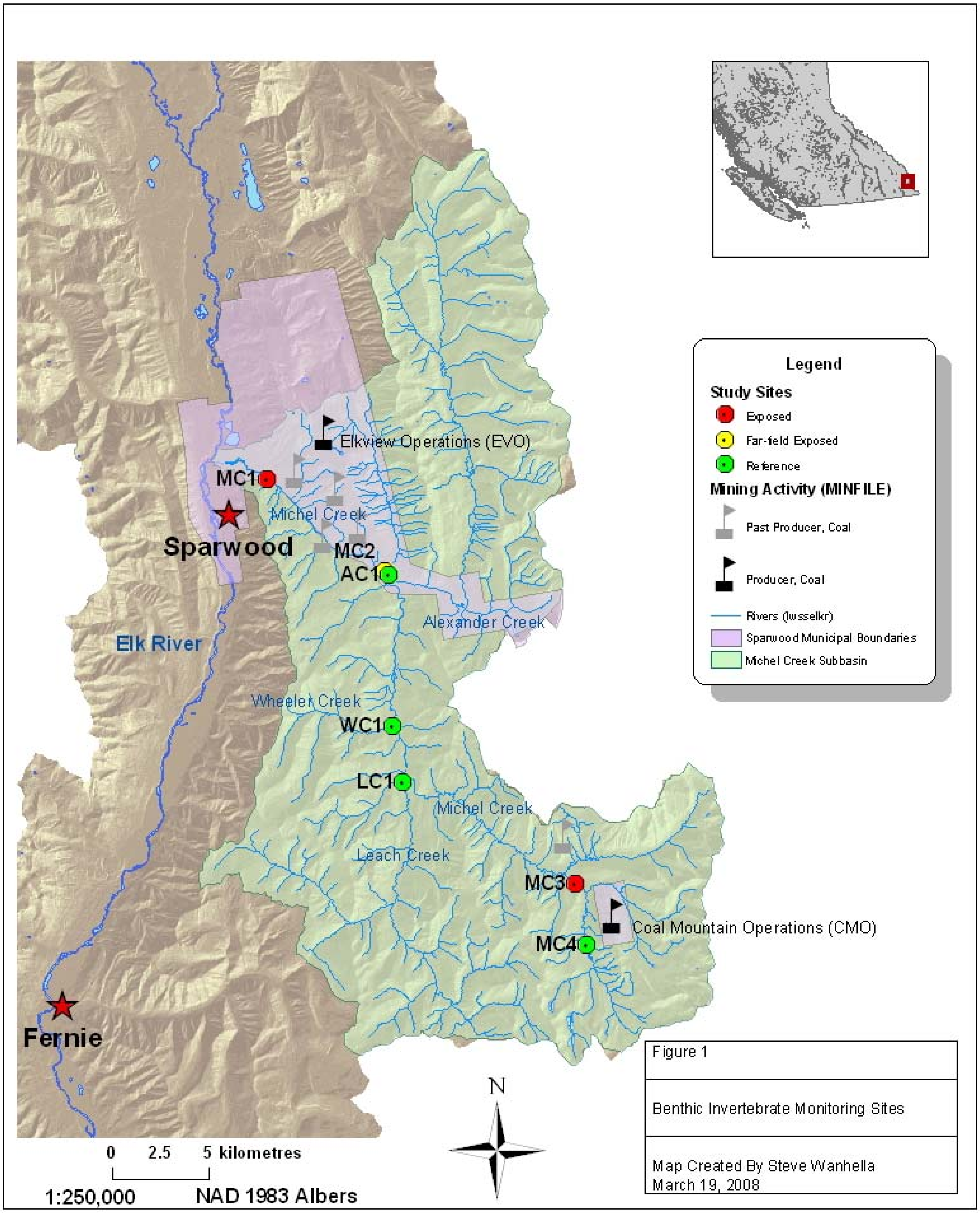


Figure 1. Map of Michel Creek Basin and Monitoring Sites

The upper Michel Creek sites (MC4 & MC3) were located in 4th order stream sections and the lower Michel Creek sites (MC2 & MC1) were located in 5th order stream sections (in British Columbia, stream order designations increase from smallest tributary flows towards the mainstem flows). Two active coal mines, Coal Mountain Operations (CMO) and Elkview Operations (EVO), are located in this basin; CMO located in the headwater and EVO located near the mouth. The Multiple Control/Impact design was used to detect differences between reference and exposed areas. As well, the sites were selected to approximate a simple gradient design (Environment Canada, 2005). Sample sites were located upstream and downstream of these mines to evaluate changes in the benthic community structure related to mining activities. In addition, three reference sites, Leach (LC1), Wheeler (WC1) and Alexander (AC1) Creeks (major tributaries of Michel Creek), were sampled in 2006 to assess natural variability; LC1 and AC1 are 4th order streams and WC1 is a 2nd order stream. Reference sites were determined by evaluating land use maps, conferring with local/regional staff of MOE and confirming minimal land use through site reconnaissance.

Prior to sampling, potential sites were evaluated and selected based on habitat with an effort to "normalize" the sites to control as many factors as possible such as depth, velocity, bankfull width, substratum type, flow, and canopy cover (Reynoldson et al., 2006). Sites were further normalized by sampling only the erosional habitats (i.e. riffles) (Barbour et al., 1999). Stream habitat variables that may affect benthic invertebrate community structure were recorded on CABIN field sheets: channel width, channel slope, water depth, flow, velocity, % canopy cover and substrate type.

Sites were photographically documented and the UTM coordinates were recorded with a global positioning system (GPS) device. All of the information collected at the sample sites, including habitat evaluation and benthic invertebrate composition, was entered into Environment Canada's CABIN database for future analysis once an appropriate reference model is established.

Temporal Aspects of Sampling Strategy

Samples were collected in September 2006 and September 2007 when the benthic community diversity and biomass was assumed to be high (Karr & Chu, 1999; Beatty et al., 2006).

Benthic Invertebrates

A Hess sampler, with a mesh size of 243 µm, was used to collect the macroinvertebrates, since abundance and diversity are important endpoints for this study (Beatty et al., 2006). Riffle habitats in all locations were sampled limiting the effect that habitat has on variations in benthic community structure (Garcia-Criado et al., 1999). At all sites, large substrate within the Hess sampler was washed to remove insects and then placed back in the stream. The remaining substrate, to a depth of 5 to 10 cm, was then gently agitated for a period of four minutes per site (MOE, 2003). Sample collection followed Beatty et al. (2006), with three replicates per site.

Once obvious large debris was removed from the samples, they were preserved immediately in a buffered (neutralized) 10% formalin solution for approximately 15 days. The replicates were then washed to remove formalin. Washed samples were then transferred into ethanol and sent to a graduate student from the University of Victoria for identification.

Taxonomy

Each sample was sorted from debris at the laboratory. The samples were sorted down to the lowest possible taxonomic level, since higher level identification can often decrease sensitivity and reduce the ability to detect subtle changes (Rosenberg & Resh, 1993). Merritt and Cummins (1996) was used for all of the identifications made to the genus level; while other reference material was used for identifications to the species level. In this study, the Hess samples were fully counted and identified.

Quality assurance and quality control (QA/QC) included the establishment of a reference collection of the benthic invertebrates identified, verification of 10% of the samples by a separate taxonomist and a 10% resort check. If the resort count was >90% of the original sort, this was considered acceptable (Environment Canada, 2002).

The QA/QC was conducted by Cordillera Consulting in September 2007. Three out of the four samples for the sorting efficiency met the 90% efficiency level, while one sample was 1.8% below the acceptable level. The taxonomic efficiency resulted in the re-counted samples being consistently lower than the original counts.

The reference collection QA/QC was exceptional. Nonetheless, five suggestions were made for re-identification of the invertebrates.

Metrics

A multimetric approach was used to evaluate benthic community structure. Since a specific biotic index to determine whether coal mining effluent has an impact on benthic invertebrates has not been derived to date (Garcia-Criado et al., 1999), sixteen metrics were selected to illustrate increasing perturbation (Tables 1 & 2). Even though the metrics selected have been used to detect disturbance in other studies, it is recommended that specific metrics need to be calibrated for different regions and even different stressors (Barbour et al., 1999). This study did not have the historical dataset necessary for this type of metric calibration. The data collected during this study can be used as a base for future metric calibrations to determine which metrics have a consistent and predictable response to coal mining activity (Karr & Chu, 1999).

The metrics selected include family richness of Ephemeroptera, Plecoptera and Tricoptera (EPT) taxa, which has been suggested as the most successful metric to detect coal mining impacts (Garcia-Criado et al., 1999). EPT taxa richness was not used in isolation since Garcia-Criado et al. (1999) concluded that further research was necessary to confirm their conclusions that EPT taxa was the best metric to evaluate coal mine impacts. Other metrics include % EPT taxa, and Ephemeroptera taxa richness as described in Merricks et al.'s (2006) assessment of coal mining effects, acid mine drainage, in headwater streams.

Metrics, such as total abundance, taxon richness, loss of sensitive taxa and functional feeding measures, were also used to evaluate the benthic community structure; these metrics are relevant since they are more likely to discriminate between biological "signals," including effects from human activity and natural variation (Karr & Chu, 1999).

Water Quality

Water quality samples were collected according to the B.C. Field Sampling Manual (MOE, 2004) during the sampling event and sent to Maxxam Analytics Inc. in Burnaby, B.C. for analysis. A QA/QC simultaneous side-by-side replicate sample was taken randomly at 10% of the total number of sites and relative percent difference (RPD) was calculated.

Statistical Analysis

Statistical analyses were done with SAS software and Excel. A one-way ANOVA and posthoc Tukey comparison was used to determine variation within sites and between sites in 2006, while one-tailed t-test was used on the 2007 data. A two-way ANOVA was used on both datasets to determine how site and year influenced the metrics. Pearson's correlation coefficient and multiple linear regression was used to determine if relationships exist between water quality variables and benthic community structure (Azrina et al., 2006) and habitat variables and benthic community structure. Since there is limited historical benthic community structure data on Michel Creek, the significant effect size was set at $p<0.05$ (Environment Canada, 2002).

RESULTS

Spatial Analysis of 2006 and 2007 Water Quality Data

During the benthic sampling events in 2006 and 2007, selected water quality variables were analyzed at all seven stations within the Michel Creek basin (Appendix 1). All four of the reference sites (MC4, AC1, WC1 and LC1) had similar water chemistry characteristics; however there were a few differences. The reference site that was most dissimilar to the others was Wheeler Creek (WC1). Wheeler Creek had an unusually high ammonia value (0.015 mg/L) compared to the other reference sites, which had ammonia levels less than the detection limit (0.005 mg/L). Total phosphorus was also unusually high in Wheeler Creek (0.021 mg/L) and below the detection limit (<0.002) at the other reference sites. Some metals were also higher in Wheeler Creek than most reference sites; these included aluminum, barium, copper, lithium and zinc.

There were some differences in water chemistry between the four reference sites; however, changes in water chemistry below coal mining activity were obviously greater than the documented natural variability. Water chemistry variables that increased below both active coal mines along Michel Creek (MC3 & MC1) included specific conductance, TDS, hardness, alkalinity, bicarbonate, calcium, magnesium, boron, sodium, chloride, dissolved sulphate, sulphur, iron, bicarbonate, nitrate, nitrite, aluminum, antimony, arsenic, cobalt, lithium, manganese, molybdenum, nickel, selenium, strontium, thallium, uranium and zinc (Appendix 1).

Among the most notable water quality changes below coal mining activity were increases in selenium and dissolved sulphate concentrations. Selenium concentration was as high as 16.2 µg/L below EVO and 3.5 µg/L below CMO, while dissolved sulphate was 237 mg/L below CMO and 93.8 µg/L below EVO. Selenium was above the B.C. Aquatic Life Guideline of 2µg/L below both of the coal mines; dissolved sulphate exceeded the B.C. Aquatic Life Guideline of 100 mg/L for dissolved sulphate below CMO.

Increased levels of nitrate and nitrite were also observed within Michel Creek below the coal mines. However, both of these variables were below the B.C. Aquatic Life Guideline maximum concentration of 200 mg/L for nitrate and 0.06 mg/L for nitrite (if chloride is less than 0.2 mg/L). Nitrate and nitrite concentrations, nonetheless, appear to be good tracers of coal mine related inputs into the watershed, at least initially before the water concentrations are influenced by natural nitrogen cycling processes such as uptake into primary producers, or denitrification.

For the most part, water quality data collected in September 2006 and 2007 fell within the ranges previously observed (McDonald, 2008) in Michel Creek downstream from the Elkview Operations (MC1).

<u>Spatial and Temporal Analysis of 2006 and 2007 Benthic Data</u>

A detailed summary of the calculated metrics for 2006 and 2007 are presented in Tables 1 and 2. Generally, all sites sampled in 2006 and 2007 were able to support a number of benthic invertebrate families and genera. Taxonomic richness ranged from 36 taxa at MC4 and MC3 to 43 taxa at MC1 in 2006; 35 taxa at MC3 to 43 taxa at MC2 in 2007 (Table 1 & 2). During both sampling events, more distinct taxa were found at the downstream sites on Michel Creek, MC2 and MC1, than the two upstream sites, MC4 and MC3. In 2006, the number of taxa remained the same above and below CMO at 36 taxa (MC4 & MC3) and increased from 37 taxa at MC2 to 43 taxa at MC1. No obvious difference in taxa richness was observed above and below the coal mines in 2007.

Mean total abundance, based on the average of three replicates, was variable between sites and ranged from 2898 at Leach Creek (LC1) down to 671 on Michel Creek (MC2) in 2006 (Table 1). In 2007, total abundance was higher overall at all four sites than in 2006 and ranged from 3232 at MC4 to 2132 at MC3 (Table 2). The difference between annual abundance was significantly different for all sites except MC1. Below both of the coal mines total abundance decreased in 2007, while a decrease was only observed below CMO in 2006.

2006 Data Collection

It was evident that EPT comprised the majority of the benthic invertebrates at most of the reference sites in 2006, typically being over 71% of the population, while immediately below coal mining activity % EPT was 49% and 56% in 2006 (at MC3 and MC1 respectively) (Table 1). However, EPT made up only

36% of the population at Leach Creek (reference site) while Dipterans (mainly Chironomidae) made up the majority of the population. Leach Creek (LC1) site was somewhat unusual compared to the other reference sites. The total abundance was more than double the total abundance of the other reference sites and the percent composition of EPT was much lower than other reference sites (Figure 2). Chironomidae was the highest at LC1 at 1545 making up 53% of the population, followed by MC1 at 508 (36%).

Table 1. 2006 Summary Metrics Based on the Average of 3 Replicates

		Reference								Exposed					
		LC1*		WC1*		AC1*		MC4*		MC3		MC2		MC1	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Composition measures	Total # Organisms	2898	34%	1311	26%	1418	26%	1683	24%	1238	40%	671	8%	1423	38%
	Total # Taxa	41	7%	39	2%	42	8%	36	10%	36	4%	37	4%	43	2%
	# EPT	975	3%	963	68%	1140	29%	1361	38%	600	30%	471	21%	783	34%
	% EPT of total	36	40%	71	38%	80	4%	80	13%	49	9%	71	30%	56	2%
	# Ephemeroptera	595	33%	328	57%	595	26%	967	35%	405	32%	245	12%	236	38%
	% Ephemeroptera	21	9%	24	28%	42	1%	56	9%	33	7%	37	21%	18	64%
Richness measures	# EPT taxa	23	3%	22	6%	24	6%	17	0%	18	8%	21	10%	22	13%
	% EPT taxa	56	4%	56	4%	58	3%	48	9%	50	4%	58	6%	50	15%
	# Ephemeroptera taxa	8	0%	7	0%	8	0%	5	0%	6	12%	7	0%	7	10%
	# Plecoptera taxa	10	7%	10	7%	8	17%	10	0%	9	8%	8	27%	9	8%
	# Trichoptera taxa	5	0%	5	14%	8	0%	2	0%	3	0%	7	0%	6	24%
Tolerance / Intolerance measures	% Dominant taxon	64	16%	46	46%	38	3%	57	10%	45	6%	40	10%	54	31%
Feeding measures	% Filterers	40	43%	4	125%	3	33%	0		0		12	75%	10	40%
	% Grazers and Scrapers	6	17%	23	135%	18	6%	10	40%	7	29%	22	14%	9	78%
Habitat measures	# Clinger taxa	17	6%	16	6%	20	15%	12	8%	12	8%	16	6%	18	6%
	% Clingers	42	2%	41	7%	48	6%	34	15%	34	9%	44	5%	41	10%

*Reference site

Table 2. 2007 Summary Metrics Based on the Average of 3 Replicates

		Reference		Exposed					
		MC4*		MC3		MC2		MC1	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
Composition measures	Total # Organisms	3232	19%	2132	11%	2450	32%	2410	15%
	Total # Taxa	36	6%	35	10%	43	12%	42	12%
	# EPT	2684	24%	1885	12%	1543	34%	1223	6%
	% EPT of total	82	4%	88	0%	63	0%	51	9%
	# Ephemeroptera	1487	44%	1000	21%	845	9%	614	7%
	% Ephemeroptera	45	24%	46	12%	35	22%	26	7%
Richness measures	# EPT taxa	20	4%	20	21%	26	11%	23	3%
	% EPT taxa	54	2%	57	11%	60	1%	55	9%
	# Ephemeroptera taxa	7	10%	7	0%	9	8%	8	0%
	# Plecoptera taxa	10	7%	9	16%	10	14%	10	7%
	# Trichoptera taxa	2	35%	4	65%	7	10%	5	0%
Tolerance/Intolerance measures	% Dominant taxon	49	8%	47	7%	42	10%	53	7%
Feeding measures	% Filterers	1	0%	1	100%	10	30%	6	17%
	% Grazers and Scrapers	14	7%	15	0%	19	26%	14	14%
Habit measures	# Clinger taxa	14	7%	16	38%	20	20%	19	11%
	% Clingers	39	0%	45	27%	47	11%	46	0%

*Reference site

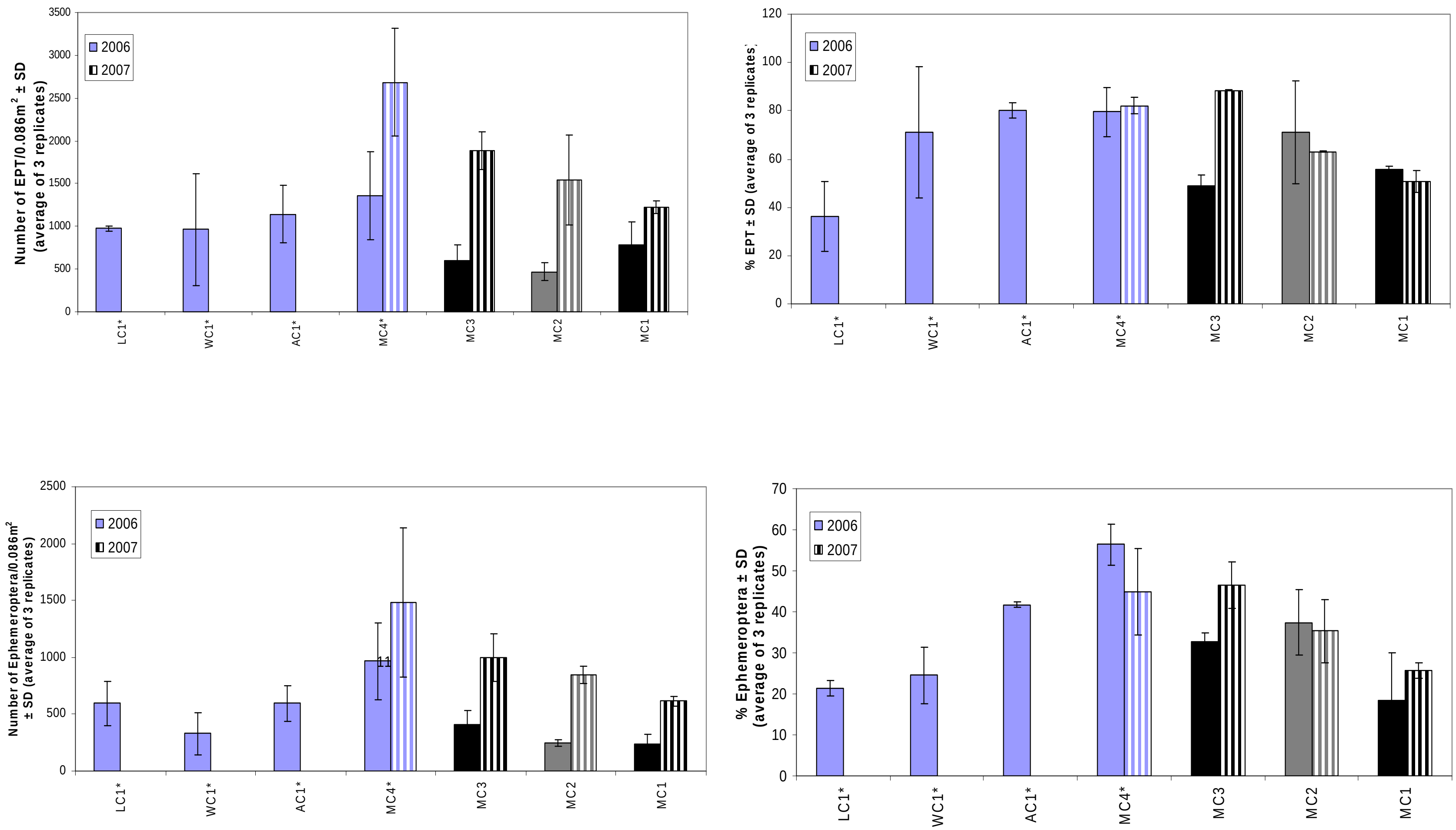


Figure 2. 2006 & 2007 Number of EPT and %EPT and Number of Ephemeroptera and % Ephemeroptera of Total Abundance

In 2006, most of the metrics below the coal mines fell within the reference range means. However, the total number of EPT at MC3 (600) and MC2 (471) were slightly below the reference range 639-1867 (Table 1). As well, the total number of organisms at MC2 (671) fell below the reference range of 905 to 3384. Even though most of the metrics below the mines were within the reference range, three metrics were close to the lower end of the range, the number of Ephemeroptera, percent Ephemeroptera, the number of EPT taxa and percent EPT taxa. Reference mean and range calculations included Leach Creek despite the unusually high abundance of organisms and low percent EPT.

Below both coal mines the % EPT, number of Ephemeroptera and % Ephemeroptera decreased (Table 1 & Figure 2). Even though % EPT and % Ephemeroptera decreased below CMO, there were signs of recovery at the far-field monitoring site (MC2). The recovery was not observed at the far-field monitoring site (MC2) for the number of Ephemeroptera. Although these metrics decreased below the coal mines, there was a slight increase in the number of EPT taxa below each of the mines (Table 1). The number of Dipterans, particularly Chironomidae, also changed below the coal mines, 197 to 415 below CMO and 145 to 556 below EVO.

Leach Creek stood out as an unusual reference site having the highest number of filtering collectors at 40%, while MC2 had the second highest at 12% (Table 1).

2007 Data Collection

Benthic monitoring in 2007 confirmed the findings in 2006, but not as clearly. In 2007, there was also a decrease in number of EPT and number of Ephemeroptera below both coal mines with no signs of recovering at the far-field monitoring site (MC2) (Figure 2). The percentage of EPT below EVO decreased, but increased below CMO. The percentage of EPT was higher at MC4 & MC3 than MC2 & MC1. The number of EPT taxa decreased below EVO from 17 to 15, but remained the same above and below CMO (Table 2).

Similarly to 2006, the number of Chironomidae changed from above to below mining activity. The number of Dipterans, particularly Chironomidae, changed from 341 to 153 above to below CMO and 611 to 940 above to below at EVO.

<u>Results Summary</u>

The changes in benthic community structure were very subtle. Sixteen different metrics were tested and only four of these showed a significant change below both of the coal mines (Table 4). The results indicate that there was a strong inter-annual component to the abundance and proportion of both EPT and Ephemeroptera; however, there was, in both 2006 and 2007, a clear indication of fewer and lower proportions of EPT and Ephemeroptera at site MC1 in comparison with the upstream reference site (MC4). The overall abundance of benthic invertebrates was higher in 2007 than 2006, while changes to benthic community structure observed in 2006 were more apparent than in 2007 (Table 4). Decreases in the number of EPT and Ephemeroptera were statistically significant below CMO in 2006. All statistically significant differences entailed a decrease in EPT and/or Ephemeroptera, except at MC1 in 2006. There was a significant increase in the number of EPT at MC1 in 2006. This was due to the overall higher abundance of organisms at MC1 compared to MC2.

Table 4. Metrics That Differed Significantly Below Coal Mining Activity

Metric	MC4 vs MC3		MC2 vs MC1	
	2006	2007	2006	2007
# EPT	p=0.03	-	p=0.03*	-
% EPT	p=0.002	-	-	-
# Ephemeroptera	p=0.04	-	-	p=0.009
% Ephemeroptera	p=0.006	-	-	p=0.03
# Ephemeroptera taxa	-	-	-	-

Notes:
$p<0.05$ statistically significant (all p values are one tailed tests)
- not statistically significant
*statistically significant increase in EPT at MC1

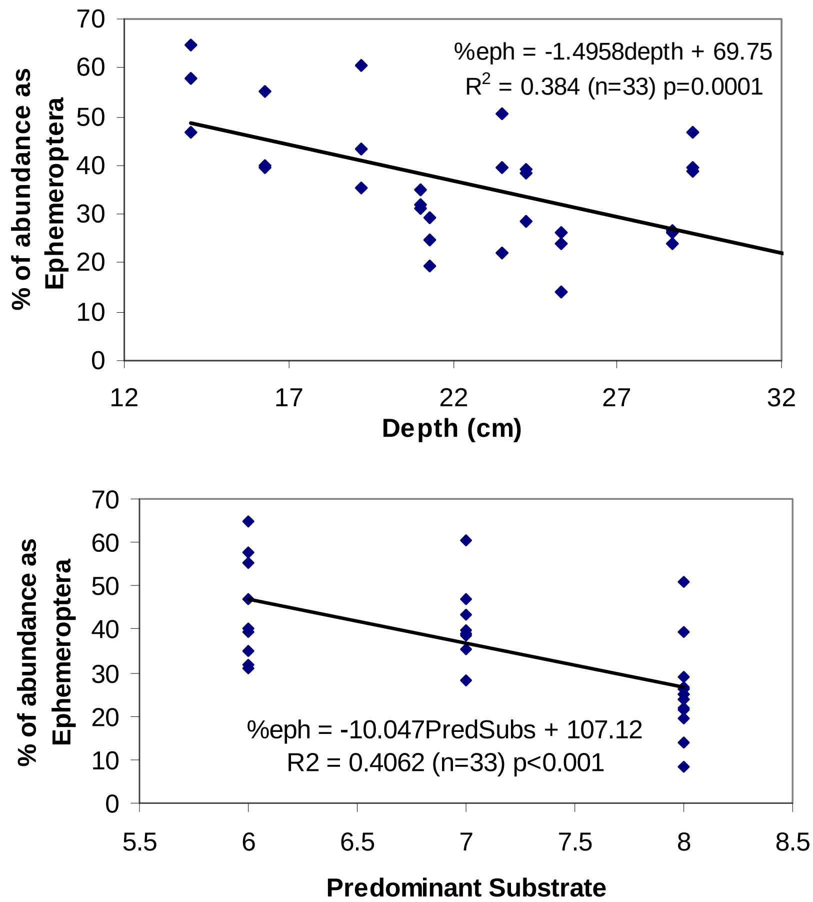
Benthic Changes Correlated with Water Quality and Habitat Variables

Once spatial differences in the abundance and proportion of both EPT and Ephemeroptera below coal mining activity were discovered, the data collected during this study was then evaluated to determine if there were any correlations between water quality variables and abundance and proportion of both EPT and Ephemeroptera and stream characteristics and abundance and proportion of both EPT and Ephemeroptera (Tables 5 & Figure 3).

Some of the strongest negative correlations were between % Ephemeroptera and stream characteristics (Figure 3).

Table 5. Pearson Correlation Coefficients Relating EPT or Ephemeroptera Densities or Proportion to Stream Chemistry

	Se	SO_4	Nitrate	Nitrite
# EPT	-0.27	-0.31	-0.22	-0.42
% EPT	-0.42	-0.31	-0.43	-0.50
# Ephemeroptera	-0.39	-0.27	-0.33	-0.38
% Ephemeroptera	-0.57	-0.13	-0.52	-0.31
# Ephemeroptera taxa	0.11	-0.33	0.12	-0.36



Source: Based on individual Hess samples and 2006 and 2007 data combined

Figure 3. Covariation Between % Ephemeroptera and Stream Characteristics

Often natural variation can account for the changes in benthic community structure; however there was a negative correlation between % Ephemeroptera and water column Se concentrations (Figure 4). In this specific case, an even stronger relationship was present without the inclusion of the extra reference sites (WC1 and LC1) which seemed to increase the extent of confounding variability as there was some natural variation that resulted in a difference between sub-watersheds, independent of coal mine inputs. The lack of a clear linear relationship may only be due to the fact that there are only a few samples at the higher concentration end for selenium concentrations.

Even though there are limitations to using same day instantaneous water samples to calculate correlation coefficients and determine linear relationships, water quality taken during the field study fell within the typical ranges found at the sample sites. Correlation coefficients and linear relationships were only evaluated for variables that were above or near the B.C. Aquatic Life Guideline and elevated below coal mining activity (selenium, sulphate, nitrate, and nitrite), therefore other indirect correlations may be present and not tested.

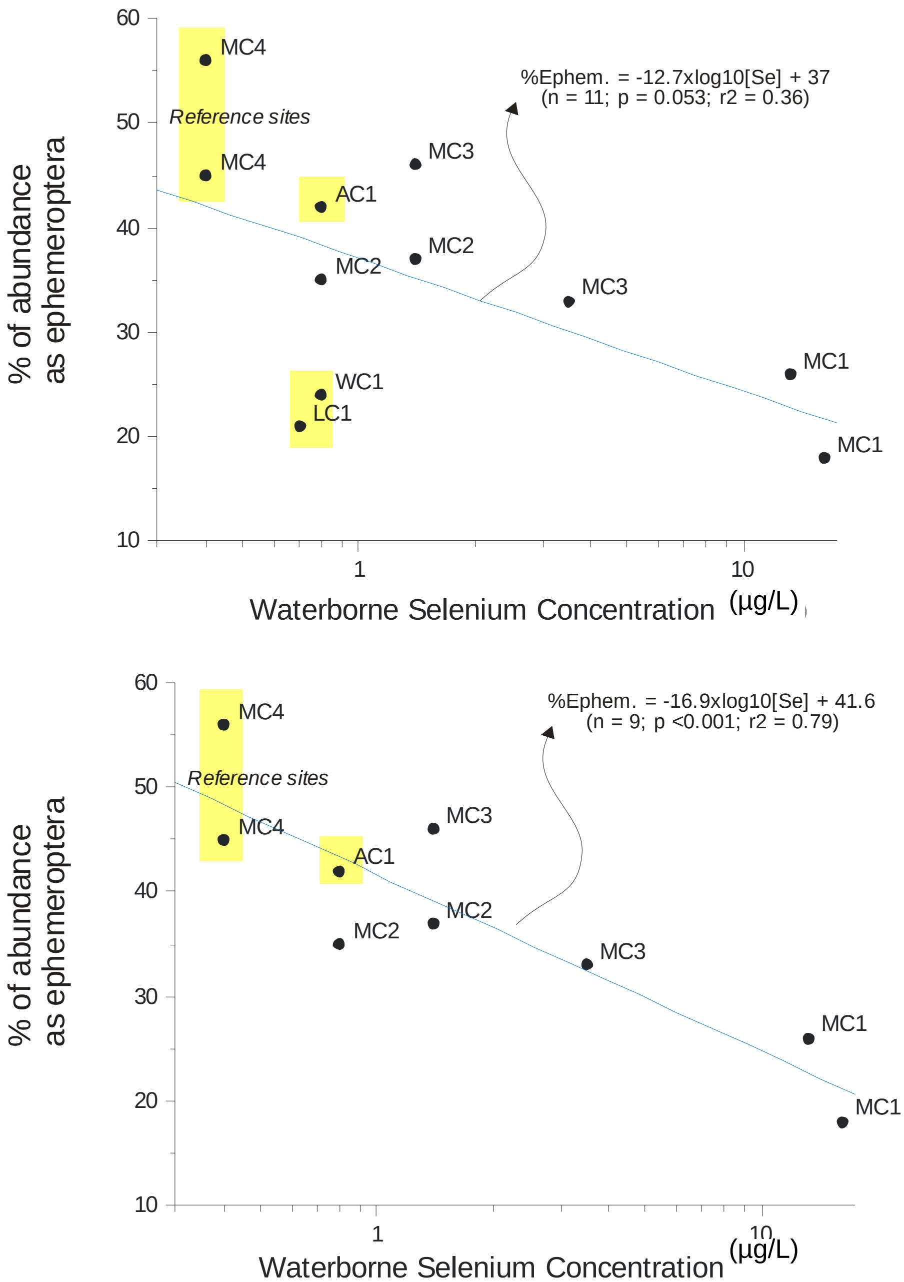


Figure 4. Relationship Between Waterborne Selenium Levels and Proportion of Ephemeroptera in Hess Samples From Four Locations in Michel Creek and Tributary Reference Areas (2006 and 2007 data): (a) Log-linear Regression Based on All Sites; (b) Log-linear Regression When Leach and Wheeler Creek Reference Sites are Excluded From the Analysis

DISCUSSION AND CONCLUSIONS

Water quality changes found below these coal mines, particularly increasing nitrate and selenium, are not a new discovery as these changes have been documented by the federal/provincial monitoring station at Highway 93, as well as McDonald (1987), Wipperman and Webber (1997) and McDonald and Strosher (1998). A detailed discussion of the water quality changes found below coal mining on Michel Creek can be found in McDonald (2008).

The range of natural variability within reference sites, as observed in Leach Creek, can be quite large, which makes it difficult to detect any subtle changes between reference and exposed sites; changes to benthic community structure were subtle compared to the water quality changes. During both sampling events, benthic communities were abundant and diverse above and below both of the coal mines and were within natural variability of the sampled reference sites, except for a decrease in sensitive species. Bradfield (1986) studied stream invertebrates in acid-generating, coal-bearing regions of Tennessee, U.S. and similarly found that tests did not indicate significant trends towards reduced number of taxa, number of organisms, and sample diversity at stations with relatively poor water-quality conditions. Chadwick and Canton (1983) also found little discernable adverse effects on invertebrates below coal mining in northwest Colorado, U.S.A.. In fact, Chadwick and Canton found an increase in total density, biomass and number of taxa from upstream to downstream of coal mining operations. Benthic communities can show high variation seasonally and annually (Maloney & Feminella, 2006) as noted in the strong inter-annual component affecting the abundance of EPT and Ephemeroptera during this study; total abundance was significantly higher at most sites in 2007 compared to 2006.

Changes in water quality and benthic invertebrate populations below coal mining in the Michel Creek basin are different than the acutely toxic impacts found in acid mine drainage. Matter and Ney (1981) and Tripole, Gonzalez, Vallania, Garbagnati, & Miguel (2006) evaluated acid mine drainage on water chemistry and benthic invertebrate populations and found a reduction in abundance and in the taxonomic richness below mining activity. Evidently, acutely toxic impacts were not observed below coal mining activity along Michel Creek as illustrated by above and below coal mining total abundance and taxonomic richness similarities.

Michel Creek illustrated biological integrity, “the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region” (Karr, 1991, p. 69). Typical signs of benthic impairment include decrease in taxa richness, decrease in intolerant and sensitive taxa and increase in dominance of a few taxa (Karr, 1999). Benthic invertebrate diversity below coal mining was similar to above coal mining and had sufficient diversity that would enable the community to accommodate changes in food availability and withstand minor perturbations. Increasing diversity correlates with increasing health of the community in that it suggests that adequate habitat and food are available to support the survival and propagation of species (Barbour et al., 1999). Nonetheless, there was a significant decrease in the number of EPT, % EPT and the number of Ephemeroptera found below the coal mines during both sampling events. This change in benthic invertebrates is a signal that something has caused a change in community structure.

The U.S. EPA Rapid Bioassessment Protocol suggests that impairment can be indicated by the absence of pollution-sensitive invertebrates, such as EPT, dominance of pollution-tolerant groups such as Oligochaeta or Chironomidae, or an overall low benthic abundance or taxa richness (Plafkin et al., 1989). Ephemeroptera are considered to be sensitive to environmental stress and their presence signifies relatively clean water conditions (Merritt & Cummins, 1978), therefore the observed decrease in EPT richness, particularly Ephemeroptera, and a general increase in Chironomidae, below the coal mines along Michel Creek indicate some level of impairment. These findings are similar to a study in southern West Virginia, U.S.A. where the % EPT, % Ephemeroptera, and Ephemeroptera richness, measures of sensitive taxa, were consistently lower at the exposed stations compared to reference (Merricks et al., 2006). Although Bradfield (1986) determined that richness was not affected consistently below coal mining, relative to a regional reference, a more tolerant community, an increase in Diptera (Chironomidae), lacking in Ephemeroptera taxa at most locations was evident. He also suggested that the % composition of Ephemeroptera and Diptera may be useful indices to evaluate the severity of impacts on invertebrate communities. Matter and Ney (1981) also found that % EPT, % Ephemeroptera and Ephemeroptera richness were consistently lower below mine exposed stations. If decreasing Ephemeroptera is truly an effect of coal mining, number of EPT, % EPT, number of Ephemeroptera and % Ephemeroptera may be possible metrics useful for detecting coal mining impacts as suggested by Garcio-Criado et al. (1999).

Preliminary evaluation of these metrics, number of EPT, % EPT, number of Ephemeroptera and % Ephemeroptera, suggests that they would be useful to evaluate the impacts that coal mining has on the aquatic environment. Because the EPT richness metrics are based on the most sensitive taxa, this would give an early warning sign if coal mine activity caused a large impact on the benthic community. The only caveat would be that the metrics often had high variability which reduces the probability of detecting effects (stat type II error) (Pratt & Bowers, 1992). EPT metrics would be even more useful in water-quality investigations once taxonomic or ecological groups of organisms can be associated with specific environmental conditions (Bradfield, 1986). This would entail a detailed study design to evaluate various levels of coal mining impact and the associated response of the EPT metrics.

In addition to changes in benthic community structure, some water quality variables, particularly selenium, sulphate, nitrate and nitrite, increased below coal mining activity. Most substances sampled along Michel Creek were below the B.C. Aquatic Life Guidelines, except selenium and dissolved sulphate.

A comparison with the B.C. Aquatic Life Guidelines for sulphate, nitrate and nitrite provide some evidence that these variables within Michel Creek are not causing direct toxicity in some of the sensitive benthic invertebrates. It is assumed that water quality problems do not exist if a substance is below the guideline (MOE, 2006). Nevertheless, nitrate could be indirectly affecting the benthic communities. Increasing levels of nitrate below the coal mines provides additional nutrients for algal growth. Since invertebrates are dependant on the condition and abundance of the primary producers, changes in the algal species can cause changes in the benthic communities. In spite of this hypothesis, nitrate and nitrite concentrations were only slightly correlated with benthic community changes. In fact, only one of the water quality variables that were elevated below the coal mines were directly correlated with changes in benthic community structure. Elevated selenium concentrations below the coal mines were well above the B.C. Aquatic Life Guideline and showed a negative correlation with the abundance and proportion of EPT and Ephemeroptera. Although not all of the water quality variables were tested for a correlation with reduced sensitive species, it is possible that the elevated selenium levels could be the cause of change in benthic community structure.

The B.C. Aquatic Life Guideline for water column selenium is 2 µg Se/L and is based on the lowest observed effect level (LOEL) of 10 µg Se/L and a safety factor of 5 that is intended to protect aquatic life from direct toxic effects and from indirect effects via the food chain. In 2001, when these guidelines were established by the B.C. Ministry of Environment, the literature indicated that the range for acute toxicity was 6 to <200,000 mg Se/L and chronic toxicity was 0.002 to 15 mg Se/L for several species of freshwater invertebrates (Nagpal & Howell, 2001). Selenium levels found within Michel Creek were the highest during this study in 2006 below EVO at 16.3 µg Se/L, followed by 3.5 µg Se/L below CMO. These levels were within the range that has been found to have toxic and chronic toxicity to some species of invertebrates.

The elevated selenium concentrations below the coal mines could partly explain the changes observed in benthic community structure, an apparent decrease in Ephemeroptera and less of an effect on Tricoptera and Plecoptera. Interestingly, in a study conducted in the Rocky Mountains of Alberta, Wayland and Crosley (2006) found that Ephemeroptera had the highest median tissue concentrations of selenium, cadmium and lead, followed by Tricoptera, and Plecoptera. Because different species can accumulate very different amounts of Se from given waterborne concentrations, this could explain the observed variability in sensitivity (Debruyn & Chapman, 2007). In this study, selenium concentrations were correlated with a decrease in the proportion of Ephemeroptera. Although the relationship was strong, with the removal of two of the reference sites, a stronger relationship could be developed if there were more sample sites with higher selenium concentrations. In fact, CMO contributes only a minor amount of the selenium load to Michel Creek, with increases only slightly higher than background levels, whereas EVO contributes most of the selenium loading to Michel Creek (Minnow Environmental Inc. et al., 2008). Sampling other sites throughout the Elk Valley would provide a greater range of selenium concentrations, possibly improving the relationship between increasing waterborne selenium concentrations and decreasing Ephemeroptera. Even though selenium could be the cause for change in benthic communities, this insight is purely speculative considering there are other factors that can cause a change in benthic community structure.

Other factors correlated with the changes in benthic communities were the habitat variables monitored, depth and the pre-dominant substrate. Because invertebrate species change with changing environmental conditions, it is well known that cause and effect cannot be easily inferred from benthic structural data (Bradfield, 1986; Chadwick & Canton, 1983; Reynoldson & Metcalfe-Smith, 1992). Often a change in physical conditions can cause a change in the energy processes and functional attributes of biota such as observed in the “stream continuum hypothesis” (Karr, 1991, p. 80). This was one of the suggested causes for changing benthic communities in Chadwick and Canton’s (1983) research, functional feeding groups changed through the study area as the energy source changed from allochthonous carbon to autochthonous carbon.

RECOMMENDATIONS

The following recommendations are suggested to maintain the ecological integrity of Michel Creek.

- As focused benthic community structure studies have not been conducted within the Elk River Valley, it would be beneficial to monitor benthic community structure above and below coal mine activity. Because of the unique water chemistry within Michel Creek, particularly high phosphorus input from Wheeler and Leach Creek, it is difficult to extrapolate the results from this study to other regions in the Elk Valley. Monitoring sites with a range of higher selenium concentrations could provide a correlation between selenium concentration and changes in benthic community structure, particularly the proportion and abundance of EPT and Ephemeroptera.

- If decreasing Ephemeroptera was truly an effect of coal mining, number of EPT, % EPT, number of Ephemeroptera and % Ephemeroptera may be possible metrics useful for detecting coal mining impacts as suggested by Garcio-Criado et al. (1999). A detailed study evaluating the effectiveness of the proportion and abundance of EPT and Ephemeroptera to improve the usefulness of this metric to assess water quality.

- The decrease in EPT below the coal mines should be investigated. Specific toxicity testing on Ephemeroptera species, possibly Ephemerellidae, to determine if selenium is actually toxic to these species.

- An evaluation of the whole river system, such as species assemblages of algae, benthic invertebrates and fish, rather than focusing solely on water quality would provide a truer measure of the impact of a large-scale influence like surface coal mining. This is particularly true within the Michel Creek system; despite most of the water quality parameters being below the B.C. Aquatic Life Guideline, except selenium and occasionally sulphate, there were changes observed within the benthic invertebrate community.

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Appendix 1. Michel Creek Basin 2006/2007 Water Chemistry Data

	EMS ID	E207787	E207788	E263381	E258175		E258937		200429		200025	
	Site Code	LC1*	WC1*	AC1*	MC4*		MC3		MC2		MC1	
Field Parameters	**Units**	**24-Sep-06**	**29-Sep-06**	**24-Sep-06**	**23-Sep-06**	**28-Sep-07**	**23-Sep-06**	**28-Sep-07**	**24-Sep-06**	**28-Sep-07**	**23-Sep-06**	**28-Sep-07**
Field Conductivity	uS/cm	200	210	310	280	296	780	477	360	366	500	547
Field Dissolved Oxygen	mg/L	9.70	7.40	11.00	14.00	11.26	12.00	11.54	13.00	11.17	12.00	11.32
Field pH	pH Units	7.70	7.90	8.10	7.50	7.02	7.70	8.42	8.10	8.08	7.90	8.05
Field Temperature	°C	7.6	7.0	8.2	7.0	5.7	4.8	7.8	8.0	9.1	7.5	9.1
Lab analysis												
Conductivity	uS/cm	208	221	329	296	294	802	470	393	365	535	562
pH	pH Units	8.2	8.2	8.3	8.2	8.3	8.3	8.2	8.4	8.4	8.4	8.4
Total Suspended Solids	mg/L	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Total Dissolved Solids	mg/L	126	-	188	180	160	566	302	236	212	342	388
Turbidity	NTU	0.1	-	0.2	0.2	0.3	0.5	0.3	0.5	0.3	0.4	0.9
Total Hardness (CaCO3)	mg/L	120	130	190	170	164	450	252	220	202	300	308
Alkalinity (Total as CaCO3	mg/L	105	118	161	140	136	189	158	158	158	174	177
Alkalinity (PP as CaCO3)	mg/L	<0.5	<0.5	1.1	<0.5	0.6	<0.5	<0.5	1.6	2.7	2.2	2.3
Bicarbonate (HCO3)	mg/L	128	144	193	170	165	230	193	189	186	207	210
Carbonate (CO3)	mg/L	<0.5	<0.5	1.4	<0.5	0.7	<0.5	<0.5	1.9	3.3	2.6	2.8
Hydroxide (OH)	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Bromide (Br)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.01	<0.1	0.02	<0.1	<0.01	<0.1	0.02
Dissolved Sulphate (SO4)	mg/L	4.9	5.1	18.9	19.9	23.0	237.0	94.1	54.2	40.3	93.8	99.0
Chloride (Cl)	mg/L	<0.5	<0.5	0.7	<0.5	<0.5	3.3	1.4	1.2	1.2	3.5	4.4
Nutrients												
Ammonia (N)	mg/L	<0.005	0.015	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005
Nitrate plus Nitrite (N)	mg/L	0.003	<0.002	0.016	<0.002	0.011	0.773	0.250	0.008	0.007	2.850	3.210
Nitrite (N)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	0.009	0.002	<0.002	<0.002	0.005	0.004
Nitrate (N)	mg/L	0.003	<0.002	0.016	<0.002	0.011	0.764	0.248	0.008	0.007	2.850	3.200
Total Phosphorus (P)	mg/L	0.008	0.021	<0.002	<0.002	0.006	0.003	0.004	0.003	0.005	0.002	0.004
Orthophosphate (P)	mg/L	0.009	<0.001	0.001	0.001	0.005	0.002	0.005	0.002	0.006	0.001	0.007
Total Metals by ICPMS												
Aluminum (Al)	ug/L	2.1	10.3	2.1	2.2	3.1	16.3	4.8	2.2	5.2	3.2	7.7
Antimony (Sb)	ug/L	0.069	0.094	0.014	0.006	0.017	0.119	0.092	0.066	0.060	0.243	0.339
Arsenic (As)	ug/L	0.3	0.3	0.2	0.2	0.2	0.4	0.3	0.3	0.1	0.6	0.2
Barium (Ba)	ug/L	132.0	187.0	68.1	51.7	52.2	90.2	58.8	131.0	115.0	118.0	127.0
Beryllium (Be)	ug/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Bismuth (Bi)	ug/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cadmium (Cd)	ug/L	0.04	0.04	<0.01	<0.01	<0.01	0.05	0.02	0.03	0.02	0.04	0.05
Chromium (Cr)	ug/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.6	<0.2	<0.2	<0.2	<0.2
Cobalt (Co)	ug/L	<0.03	<0.005	<0.03	<0.03	<0.005	0.564	0.013	<0.03	0.008	0.006	0.063
Copper (Cu)	ug/L	0.21	0.64	0.08	0.06	0.09	0.15	0.22	0.22	0.25	0.15	0.18
Lead (Pb)	ug/L	0.03	<0.01	0.04	<0.01	<0.01	0.07	0.09	0.02	0.02	0.02	0.05
Lithium (Li)	ug/L	1.42	4.88	3.47	3.35	3.93	8.73	5.19	4.87	5.24	10.70	15.60
Manganese (Mn)	ug/L	1.36	1.02	0.79	1.84	1.73	12.70	1.23	0.90	1.60	2.86	3.06
Molybdenum (Mo)	ug/L	0.60	0.98	0.63	0.66	0.71	0.89	0.79	0.68	0.76	1.56	2.05
Nickel (Ni)	ug/L	<0.05	0.31	<0.3	<0.05	0.18	3.78	0.25	<0.05	0.29	2.19	3.57
Selenium (Se)	ug/L	0.7	0.8	0.8	0.4	0.4	3.5	1.4	1.4	0.8	16.2	13.2
Silver (Ag)	ug/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Strontium (Sr)	ug/L	61.1	75.3	125	131	124	308	186	164	152	186	194
Thallium (Tl)	ug/L	<0.002	<0.002	<0.002	<0.002	0.003	0.018	0.018	0.01	0.004	0.013	0.012
Tin (Sn)	ug/L	<0.01	0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01
Uranium (U)	ug/L	0.229	0.303	0.613	0.348	0.343	1.490	1.070	0.561	0.636	1.280	1.690
Vanadium (V)	ug/L	0.20	0.26	<0.06	<0.06	0.17	0.16	0.26	0.22	0.23	0.20	0.25
Zinc (Zn)	ug/L	<0.5	0.6	<0.5	<0.5	<0.1	0.4	<0.1	<0.5	<0.1	<0.5	0.2
Total Metals by ICP												
Boron (B)	mg/L	<0.008	<0.008	<0.008	0.0110	0.0100	0.0270	0.0100	0.0100	0.0090	0.0160	0.0140
Calcium (Ca)	mg/L	31.4	33.2	53.4	43.1	42.9	111.0	68.4	62.1	56.7	78.1	78.1
Iron (Fe)	mg/L	<0.005	0.020	0.017	<0.005	0.005	0.074	0.010	0.009	0.048	0.023	0.018
Magnesium (Mg)	mg/L	9.11	10.7	14.4	14.1	13.8	42.1	19.8	16.2	14.7	26.6	27.5
Phosphorus (P)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Potassium (K)	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	1
Sodium (Na)	mg/L	0.80	1.29	1.97	2.90	2.76	10.50	3.92	3.49	2.68	3.74	3.40
Sulphur (S)	mg/L	1.8	1.9	6.5	7.0	7.7	80.7	33.6	18.0	13.2	33.6	36.3
Titanium (Ti)	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003

*Reference sites