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THE ENVIRONMENTAL EFFECTS OF ROCK DRAINS: RESULTS FROM THE ROCK DRAIN RESEARCH PROGRAM

Murray Fitch, M.A.Sc., P.Eng., Mike Thompson, M.A.Sc., P.Eng., Mark Kavanagh, M.Sc, P.Biol.[1]
Bill Kovach, Environmental Planner[2]

[1]Piteau Engineering Ltd.
Suite 100, 4500 16 Ave N.W.
Calgary, AB T3B 0M6

[2]Manalta Coal Ltd.
Line Creek Mine
P.O. Box 2003
Sparwood, BC V0B 2G0

ABSTRACT

The efficient disposal of waste rock at coal mines is of significant economic importance and may mean the difference between a viable and uneconomic mine. When blast rock is disposed of in a valley bottom through which a watercourse passes, the base of the dump is referred to as a "rock drain". The use of formal rock drains to convey significant streamflows at mines in the mountainous regions of western Canada dates from 1980. Since then, rock drains have come into use at the majority of Rocky Mountain coal mines in Alberta and British Columbia.

The Rock Drain Research Program was the first comprehensive study of the physical and flow-through characteristics of rock drains and their environmental effects. The program involved analysis and intensive field data collection (over a four year period) at Manalta Coal Limited's Line Creek Mine in south-eastern British Columbia.

The project comprised investigations into the physical, flow-through, and environmental characteristics of rock drains. Potential environmental issues included rock drain effects on suspended solids and bedload, water temperature, water chemistry, aquatic invertebrates, and fish.

This paper will present an overview of the "environmental effects" investigations of the program. These effects, though measurable in most cases, were found to be much less significant than initially

anticipated. Apart from the physical reduction of aquatic habitat due to the presence of the drain, the impacts of the drains were found to be quite localized.

INTRODUCTION

The Rock Drain Research Program was the first comprehensive study of the physical and flow-through characteristics of rock drains and their environmental effects. Field data were collected at Manalta Coal Limited's Line Creek Mine in south-eastern British Columbia (Figure 1).

The program was formally initiated in 1992 with final reporting in 1997. The program was jointly funded by Manalta Coal, the governments of Canada arid British Columbia, and Komex International Ltd.

The Line Creek mine is located in a subalpine valley near the town of Sparwood, in south-eastern British Columbia, Canada. The drainage basin of Line Creek ranges from approximately 1300 to 2300 m, and lies just to the east of the continental divide. Average annual precipitation at the site was 533 mm (1983-97), and mean monthly air temperatures range from a low of -11 C in January to a high of 13.7 C in August.

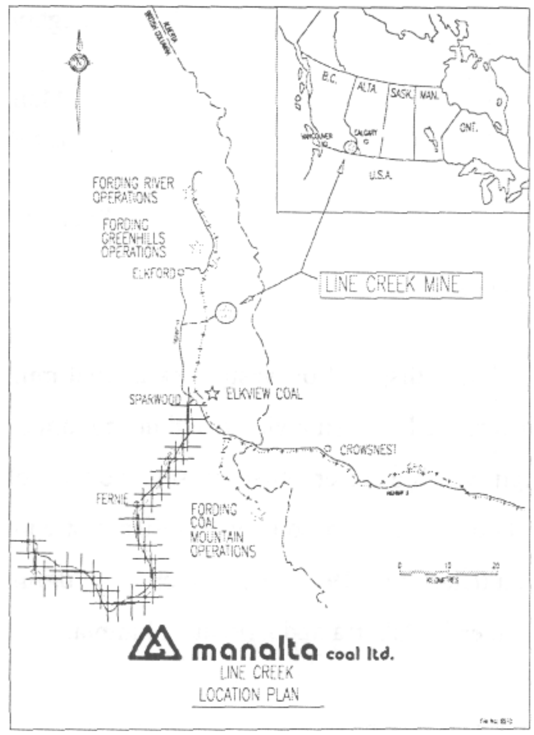

Figure 1: Location of Line Creek Mine, B.C., Canada

The primary focus of the study were the two drains on Line Creek, called the "Main Rock Drain" (MRD) and the "Rock Drain Extension" (RDE) (Figure 2). The MRD was the original drain on Line Creek, dumping having commenced in 1990. Construction of the RDE, lying upstream of the MRD, was constructed in 1994. The changing drain configurations presented significant problems for data analysis, but also the opportunity to examine the effects of drain length on a variety of environmental variables.

The Line Creek drainage is comprised of a number of tributary streams, the most significant of these being Line Creek and South Line Creek, which join downstream of the rock drain. Other tributaries include No Name Creek, which now discharges into the RDE, and West Line Creek, which enters

Downstream of the MRD. A small portion of No Name Creek is covered by rock drains, while virtually the entire West Line Creek drainage is covered by a rock drain. West Line Creek was of particular interest with respect to water quality concerns.

Line Creek is a high energy mountain stream, with a bed slope of approximately 2-3% through the areas occupied by rock drains. The stream bed is relatively coarse (typically gravels and larger). The mean annual flow at the Water Survey of Canada (WSC) gauging station (drainage area= 138 km^2) is 2.1 m^3/s, with mean monthly flows varying between 0.5 m^3/s in February and 7.9 m^3/s in June. Average flows at the downstream end of the MRD are approximately half of the WSC discharges.

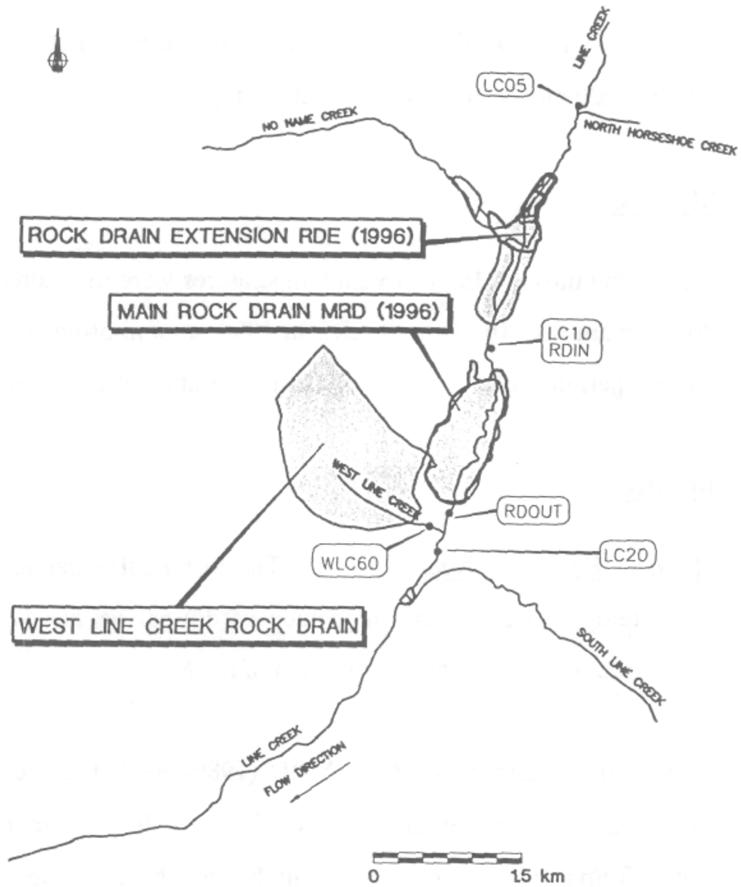

Figure 2: Line Creek Site Plan

WATER TEMPERATURE

The thermal regime of a stream has significant ecological effects on aquatic biota. Cold-blooded organisms such as aquatic invertebrates and fish are particularly sensitive to temperature change. Depending on the length and severity of the temperature change, an organism's metabolism, growth, reproduction, and distribution may be affected. Temperature changes upstream can alter the existing aquatic community downstream. If the resulting temperature changes are beyond the existing organisms' range of tolerance, their numbers will decrease and more tolerant organisms may colonise the area.

It is reasonable to assume that temperatures within the rock drain are less variable than ambient temperatures. While the drain is highly porous to air, the huge mass of rock within the drain probably reacts slowly to changes in outside temperature. Consequently, one would expect a reduction in short-term variations in water flowing through the drain, but an increase in longer-term thermal effects. Lastly, when water flows through the drain during the day it does not receive heat inputs from the sun, resulting in a relative reduction in downstream water temperatures.

Methods

From 1989 through 1994, stream temperatures were monitored at 15 minute intervals upstream (LCl0) and downstream (LC20) of the MRD. In 1994, a monitoring station was added upstream of the RDE (LC05), thereby permitting an examination of temperature effects of both drains.

Results

Mean Daily Water Temperatures: The historical water temperature data indicate that both mean daily water temperature and the magnitude of diurnal variations in water temperature have decreased at the downstream site since the construction of the MRD.

Prior to the construction of the MRD (1989-1990), the average temperature increase between LCl0 and LC20 was between 0.80 and 0.96 ^{0}C. This rise in temperature was likely due to heating directly from the sun or from residual heat in the stream bed and banks at night. By 1992, the temperature increase had been reduced to 0.18^{0}C and by 1993 there was actually a very slight decrease in mean daily temperature between LCl0 and LC20. The previous heating which had occurred in the stream prior to rock drain construction was effectively eliminated and by 1993 mean daily temperatures at the two sites were comparable.

Diurnal Variations in Water Temperature: The 1989 data, prior to rock drain construction, indicates that water temperature at both sites followed a cyclic pattern with the lowest temperature early in the morning and a peak temperature around mid-day. Upstream water temperatures were consistently lower than downstream temperatures and both showed a maximum average diurnal variability of 3 to 4 ^{0}C.

In 1992, after two years of rock drain operation, upstream temperatures followed the same cyclic pattern as seen prior to rock drain construction, while downstream temperatures fluctuated less. For example, the maximum variation in water temperature in June was approximately 2.5 ^{0}C at LC20.

The 1993 and 1994 average hourly water temperatures show a trend similar to the 1992 data. Downstream variation in water temperature was less than variation upstream. The temperature variation in LC05, upstream of the RDE, exhibited a slightly greater diurnal variation than LCl0 and LC20.

Discussion

The thermal regime of a stream is actually a composite of absolute temperature, amplitude of temperature changes, and rates of change that vary over time and with position in the water course. A variety of hydrological, topographical, and meteorological factors affect the thermal pattern seen in undisturbed stream systems. The aquatic invertebrate and fish community in Line Creek has evolved life histories consistent with the local thermal regime. An altered thermal regime has been shown to adversely affect aquatic communities.

Temperature changes of the magnitude found in the temperature study are not likely to result in measurable impacts on the aquatic community for a number of reasons. The magnitude of the changes in water temperature is small. The average temperature reduction of approximately 1°C across the MRD is simply not significant enough to cause substantial ecological effects. As well, prior to construction of the drain, there was a natural increase in temperature between LCl0 and LC20 of approximately 1°C and although the drain has eliminated this natural temperature increase, it has not shifted the mean temperature outside the range which was previously found. Diurnal variability has been reduced, but once again the temperatures are within the ranges previously found within this section of the creek. Lastly, temperatures in the creek have been reduced, rather than increased. Studies have found that salmonid species are more likely to be adversely affected by significant temperature increases, rather than decreases.

WATER CHEMISTRY

Concerns regarding water quality effects of rock drains are focused primarily on (i) acid-rock drainage and (ii) nitrogen additions. A potential for acid-rock drainage occurs when sulphide-rich rock is mined. Under aerobic conditions, sulphur can be converted by bacteria to sulphuric acid. Acidic water promotes leaching of metals from rocks. A second water quality concern is the contamination of water by nitrogen residues from ammonia nitrate based explosives used in blasting. The waste rock which forms the rock drain has surficial blasting residues and concern has been expressed that these residues may leach nitrogen compounds into surface water. Nitrogen is expected to be primarily in the form of nitrate, although both ammonia and nitrite forms are also possible. Nitrite and ammonia are more toxic to aquatic life than is nitrate, but react quickly with oxygen to form nitrate. It is unlikely that streams flowing through a rock drain will pick up enough nitrogen residue to cause an impact under normal flow conditions for two reasons: (i) the large rocks which form the base of the drain have a low surface area to volume ratio and, therefore, are covered with a relatively small proportion of the total nitrogen residue load; and (ii) only a very small proportion of the total dump is contacted by the stream.

Nitrogen loading of the streams may be expected to increase under flood conditions when higher water levels in the drain result in water contacting "fresh" rock within the dump which may have nitrogen residues. Water seeping through the dump surface (where the fine particles are concentrated) may also be elevated in nitrate. These effects are expected to be short-lived and will continue only until the blasting residue is leached from the rock surface.

Methods

Water samples were taken regularly at a number of locations on the mine site as a part of license requirements and analyzed for several parameters. Data from the mine from 1980 through 1995 were incorporated into the water chemistry database. Most of the RDRP-specific water quality data were collected in 1993, with ten samples collected at the upstream and downstream ends of the MRD, and a variety of samples collected at other locations (such as the No Name and West Line Creek drains). The range of chemical analyses included major ions, metals, and some organics (e.g. phenols and DOC). Results are presented only for the 1993 data set.

Results

Major Ions and Indicator Parameters: The major ions (calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulphate) typically constitute the majority of dissolved ions in both surface and groundwaters. All sites but WLC60 (the outlet from West Line Creek) showed similar major ion chemistry. The two WLC60 samples were significantly higher in sulphate and more highly mineralized than the samples from the remaining sites, perhaps reflecting the long residence time within the drain.

Nitrate-N: WLC60 has much higher concentrations of nitrate-N than the other sites, though the concentration is below the Canadian Drinking Water Guideline of 10 mg/L. A small increase in nitrate occurred as water passed through the MRD - the median increase was approximately 0.15 mg/L, with an average outlet concentration of 0.3 mg/L.

Total Dissolved Solids (TDS): As was the case for nitrate and sulphate, the TDS concentrations at WLC60 were substantially higher than at the other sites. The median TDS concentration at WLC60 is near the Drinking Water aesthetic objective of 500 mg/L, while the other sites are well below this level. The data shows a quite small, but relatively consistent increase in TDS across the drain which is of little concern.

Trace Parameters: Typically, metals and other trace parameters are introduced into water by leaching under acidic conditions. Line Creek, No Name Creek, and West Line Creek are all somewhat alkaline. Slight increases in concentrations across both the No Name and Line Creek Rock Drains were noted for most parameters, but the levels were typically well below the BC water quality criteria for aquatic life .

Discussion

The Line Creek drains have a small but measurable effect on the water chemistry of Line Creek. Nitrate levels were found to increase a small amount across the drain; dissolved solids concentrations differed little across the drain; and the pH is alkaline, suggesting good buffering capacity and few concerns about acid rock drainage. There may be some flushing of nitrogen compounds during high flow events, but it would appear that if this were to occur, the effects would be very short-lived.

AQUATIC INVERTEBRATES

This program investigated the effects of the Line Creek rock drains on the invertebrate drift, benthic invertebrates, transport of organic carbon in the form of coarse particulate organic matter (CPOM), and the potential effects on the invertebrate prey of resident fish.

Methods

In 1993, two invertebrate drift sites (upstream and downstream of the MRD) were assessed for the variability in basic ecological parameters. In 1994, a third sampling site was added 70 m downstream from the toe of the MRD. In 1995, benthic invertebrate samples were also collected. Invertebrate drift was not assessed, although drift samplers were used to collect coarse particulate organic matter (CPOM). Stomachs of cutthroat trout were also collected in 1995 to determine the preferred invertebrate prey taxa of these fish. A comparison of upstream and downstream abundance of these taxa was conducted.

For each invertebrate sample, the following basic ecological parameters were assessed: total invertebrate abundance, number of invertebrate taxa, total abundance and number of taxa of the particularly sensitive orders (Ephemeroptera, Plecoptera, and Trichoptera (EPT index)), and the Shannon Diversity Index.

Results

Invertebrate Drift Abundance, Number of Taxa, and Diversity: In 1993, drift samples were taken from upstream and downstream of the MRD. Statistically, there was no significant difference in abundance between the two sites. The average number of taxa and EPT counts were similar to that of total counts showing larger numbers downstream, but no significant difference between the two sites. The calculated diversity values showed a more even distribution of individuals in the taxa at the upstream site, but the difference was not statistically significant.

In 1994, drift samples were taken from upstream, downstream, and at the toe of the MRD. The downstream samples had the lowest total invertebrate count while the toe site had the largest. A statistically significant difference occurred between the toe and downstream sites. The highest number of invertebrate taxa was found in the upstream drift samples and the fewest in the downstream samples. A significant difference occurred between the upstream and downstream sites. The Shannon Diversity Index values showed a more even distribution of individuals in the taxa at the downstream site than at the toe site. A significant difference occurred between the upstream and toe sites. EPT counts were lowest for the downstream site and highest at the toe. The upstream site had the largest number of EPT taxa while the toe and downstream sites had fewer. Statistical analysis showed no significant difference between any sites for the 1994 total EPT counts, and significant differences between upstream and toe sites and upstream and downstream sites for the number of EPT taxa.

Benthic Invertebrate Abundance, Number of Taxa, and Diversity: Total benthic invertebrate abundance was lowest at the downstream site and highest at the toe of the MRD. A significant difference occurred between the toe and downstream sites. The abundance of EPT in the benthic samples was lowest upstream and highest at the toe of the MRD. Significant differences occurred between the upstream and toe as well as upstream and downstream sites. The largest number of invertebrate taxa in the benthic samples was found at the toe of the MRD while the least was found at the downstream site. Statistical analysis indicated no significant difference between sites. The Shannon Diversity Index values calculated for the downstream and toe sites showed a more even distribution than the upstream site. A significant difference occurred between the upstream and downstream sites as well as the upstream and toe sites.

Coarse Particulate Organic Matter Analysis: The largest amount of organic matter collected in drift samples came from the downstream site and produced a significant difference between it and the other two sites. There was no significant difference between the upstream and toe sites.

Cutthroat Trout Gut Content Analysis: There were significant differences in the benthic counts of several invertebrate prey taxa between the upstream and downstream sites.

Discussion

Drift and Benthic Invertebrates: If the rock drains had an adverse effect on invertebrate drift or the benthic invertebrate community, it would be expected that the site immediately downstream of the MRD would have a lower abundance of invertebrates, fewer number of taxa, and lower diversity than the upstream site. These trends were not seen in the invertebrate drift data collected for this program and a statistically significant difference in the total number of invertebrates in the benthic community was found only between the toe and downstream sites. This suggests that any influence of the MRD on these basic ecological parameters is within the range of that found in the upstream reach.

The number of individuals in the EPT taxa was smaller upstream than downstream of the MRD. If the rock drain was the cause of an adverse effect, the numbers at the toe should be less than the other two sites. This suggests that differences between the benthic invertebrate communities may be related to factors other than the rock drain.

Coarse Particulate Organic Matter: If the rock drain had an effect on the transport of CPOM, it would be expected that the toe site would have the least CPOM due to a filtering effect. There was significantly *less* CPOM in the drift upstream of the MRD than at the toe and downstream sites. The results suggest that any effect of this rock drain on the mass of the transported CPOM is negated by the input from riparian vegetation immediately downstream of the rock drain.

Cutthroat Trout Stomach Contents: If the MRD influenced the availability of invertebrate prey it was expected that the total abundance and number of these taxa would be less at the toe and increase further downstream. It was found, however, that the preferred prey species were significantly *more* abundant in benthic samples at the toe site than further downstream. Furthermore, several of the species found downstream did not exist in the upstream samples. In 1993 and 1994, there was no significant difference in the abundance of these preferred prey species in the drift samples collected. It is important to note, however, that the volume of food in the cutthroat trout stomachs was very small and was collected only once. The data must therefore be viewed with caution.

General Findings: In this program, the MRD did not appear to significantly affect invertebrate drift and the benthic community in the manner expected. There were no significant differences in any of the ecological parameters assessed between invertebrate drift upstream and downstream of the rock drain. While significant differences between benthic invertebrate populations were found upstream and downstream of the MRD, the rock drain itself did not seem to be the cause of these differences. These results suggest that any influence of the rock drain on the invertebrate drift and benthic invertebrates is small and does not exceed the natural variation of populations within the stream. Any effect of the rock drain on the transport of CPOM was rapidly ameliorated downstream by the input of additional leaf litter.

FISHERIES

Line Creek supports indigenous populations of bull trout *(Salvelinus confliientus),* westslope cutthroat trout *(Oncorhynchus clarki lewisi),* and mountain whitefish *(Prosopiwn williamsoni)* (B.C. Research 1977, and Allan 1987). The cutthroat trout population is largely resident (Allan 1995), whereas the whitefish population is present in the stream only during spring/summer (Allan 1987, and 1995). The bull trout population consists of resident rearing juveniles and an adult spawning cohort that inhabits Line Creek from mid summer to September (Allan 1987, 1991a, 1991b, 1993).

Minor changes in density and distribution of cutthroat and juvenile bull trout have been attributed to natural variation, with the exception of those losses incurred by burial of habitat beneath the Line Creek rock drains. In fact, perhaps due to fishing restrictions on the creek, fish populations doubled in 1991 and again in 1995 (Allan 1991, 1995), and continue to remain healthy and viable.

CONCLUSIONS

Despite their huge size and appearance, the environmental impacts of the two Line Creek rock drains are not as substantial as had been initially anticipated. Small changes in temperature and water chemistry were observed across the drains, but contrary to expectations, there were minor (if any) effects on the benthic invertebrate community and the downstream fishery.

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