

Coal mine drainage: complex effects on streams

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Coal has been mined in New Zealand for over a century and has become an increasingly important economic resource to the country. About half of New Zealand coal is used within the country for electricity production and by the steel and dairy industries. The other half is exported, primarily to Asian countries such as Japan and India. New Zealand coal production has increased in recent years to over 5 million tonnes, and revenues have grown markedly because of the rise in production and higher prices for energy supplies. Coal mining has obvious economic benefits to New Zealand, but there are environmental costs as well. In this article we discuss the effects of coal mining on the ecology of streams receiving runoff from mines, primarily focusing on acid mine drainage from active and abandoned mines.

Mine drainage can impose a number of severe stressors that can affect stream ecosystems. It is often acidic, and low pH waters are harmful to many organisms. Mine drainage also frequently contains high amounts of heavy metals, which can be in either dissolved or solid form in receiving streams. We describe these main stressors from mine drainage in more detail, and then discuss the effects of mine drainage on aquatic life in New Zealand streams.



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Stressors from mine drainage

Coal deposits and their surrounding rocks frequently contain pyrite, an iron sulfide mineral commonly known as fool's gold. The iron and sulfur in pyrite can react with oxygen and water to form sulfuric acid. This reaction occurs naturally, but mining activities may increase its occurrence by exposing more pyrite to oxygen and water. The acid produced by this reaction leads to the commonly used terms, acid mine drainage or acid rock drainage. However, not all water draining from mining areas will be acidic. If pyrite is not abundant, mine drainage can be of neutral pH. Alternatively, if basic minerals



Figure 1 - Iron oxide or "yellow boy" coating the substrate of Wellman Creek near Reefton

such as calcite are also present in the local rocks, the sulfuric acid will be neutralised to higher pH depending on the balance between pyrite and basic minerals. The pH of water draining a given mine will thus be determined by the geology of the deposit, and its interaction with the local hydrology.

Some streams, such as many of those on the West Coast of the South Island, are naturally low in pH. These brown-water streams are coloured because of humic and fulvic acids (sometimes called tannins) that are derived from vegetation and soils in the catchment. The pH of brown-water streams is often in the 4 to 6 range (while neutral pH is 7). Streams affected by acidic mine drainage can have pH values down to below 3.

In addition to low pH, mine drainage often contains high concentrations of metals, which can include iron, aluminium, manganese, zinc, nickel, copper, arsenic, and others. These dissolved metals can be toxic to aquatic biota if present at high concentrations. As with pH, the local geology determines which metals are likely to be dissolved in mine drainage. Some metals, once present as sulfides like pyrite, are liberated when the sulfide is oxidised upon exposure to air and water. Also, most metals dissolve more readily in acidic water. The pH and metal content of mine waters are often closely related; the most acidic waters usually have the highest metal concentrations.

In mine drainage the metals iron and aluminium are almost always present in high concentrations. At low pH, these metals are very soluble in water and are simply transported downstream. These metals become less soluble with increasing pH, and usually precipitate out of solution at certain pH thresholds. The precipitates, often iron and aluminium hydroxides or more complex chemical compounds, can be referred to generally as metal oxides. To the passerby, the presence of metal oxides is often the most distinguishing characteristic of mine drainage. The bright orange colour of streambeds, due to iron oxides, led people to call it "yellow-boy" (Figure 1). Metal oxide precipitates are generally not toxic to aquatic biota, but they can alter the streambed. Metal oxides can coat the streambed and clog the areas around rocks where animals like to live, leading to poor habitat for all aquatic life.

In some cases, other stressors from coal mining activities can affect streams. Sediment can erode from active mining areas or bare mine tailings, leading to high turbidity and fine sediment in streams. Coal fines may also make their way into streams from active mines. One key aspect of mine drainage is that the reactions that lead to high acidity and metal concentrations can still occur well after mining operations have ceased. Pyrite and other minerals are slowly oxidised on geological timescales as long as the minerals are exposed to air and water. Thus, problems with mine drainage can continue for decades or even centuries after the end of mining.

Effects on stream ecosystems

Stream ecosystems have different types of life, from bacteria to fish, which interact to form food webs. Energy to drive stream food webs comes from two main sources. The first is photosynthesis by algae and plants within the stream. The second is terrestrial material such as leaves and wood that fall or are blown into the stream; these dead materials are quickly colonised by microbes. These two energy sources are consumed by small insects and other invertebrate animals, which are in turn consumed by fish, predatory invertebrates, and other animals such as birds. The effects of mine drainage on stream life can be obvious and direct or more subtle and less direct. Direct effects include toxicity because low pH or high metal concentrations may be lethal to organisms. Indirect effects

can occur if the mine drainage affects the food supply (for example, invertebrates for a fish) or habitat for stream organisms.

Algae and microbes

Algae and microbes (bacteria and fungi) form the base of most stream food webs. Algae convert sunlight into biochemical energy, and the microbes decompose dead material such as leaf litter and wood. Algae and microbes both serve as food for different groups of stream invertebrates. A recent study on West Coast streams has found a shift in algal species going from highly stressed, low pH streams to pristine, neutral pH streams (Figure 2). In streams affected by mine drainage, some algae and microbes are often very common. Certain green algae, such as *Klebsormidium* (Figure 3), are highly tolerant of low pH and elevated metal concentrations. However, algae are less common in areas with large amounts of metal oxides precipitating onto the streambed. This physical stress caused by a coating of metal oxides appears more inhibitory to algae and microbes than the low pH or dissolved metals in mine drainage.

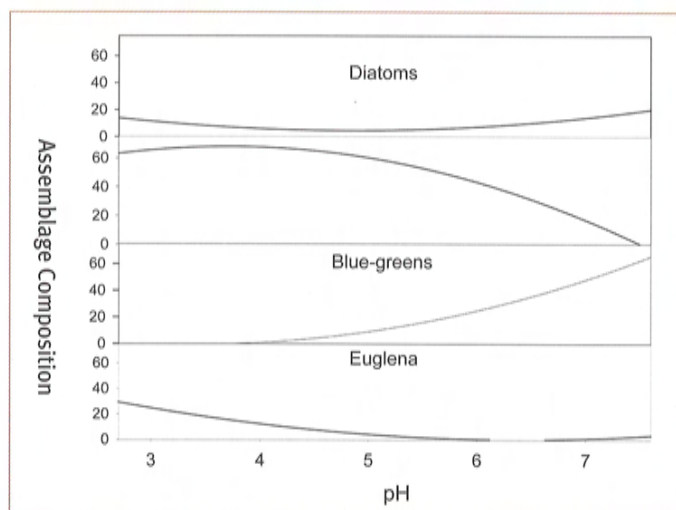


Figure 2 - Different algal groups show strong pH preferences (modified from Bray 2007)

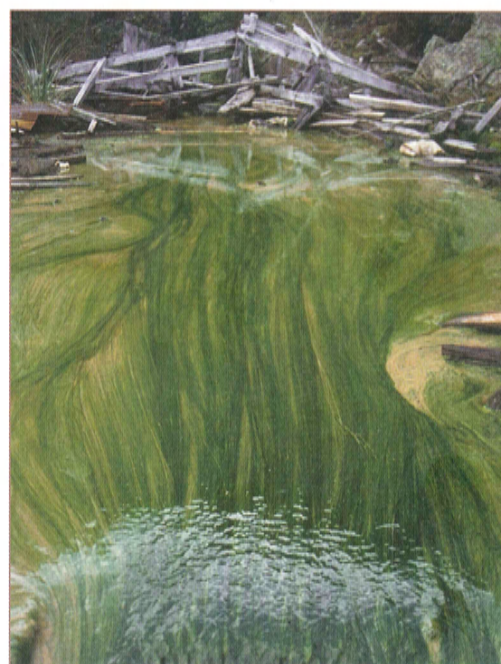


Figure 3 - A filamentous alga *Klebsormidium* is able to form dense mats in acid mine waters of low pH but stable flows

Invertebrates

Invertebrate animals are the link in stream food webs between algae (and microbes) and larger animals, including most fish. They include insect larvae, crustaceans such as crayfish and amphipods, snails, worms, and other taxa. Certain invertebrate taxa, including some stoneflies, caddisflies, and midges, appear to be quite tolerant of low pH, and are found in some streams with pH less than 4. However, there is usually a decline in the number of species as pH decreases (Figure 4). Many invertebrates are also sensitive to metal concentrations, and a decline in the number of species is seen in streams with increasing metal concentrations.

Toxicity tests with one of the most common insects found in New Zealand streams, a mayfly called *Deleatidium*, have confirmed that this important organism cannot survive in some untreated mine drainage. It is also killed

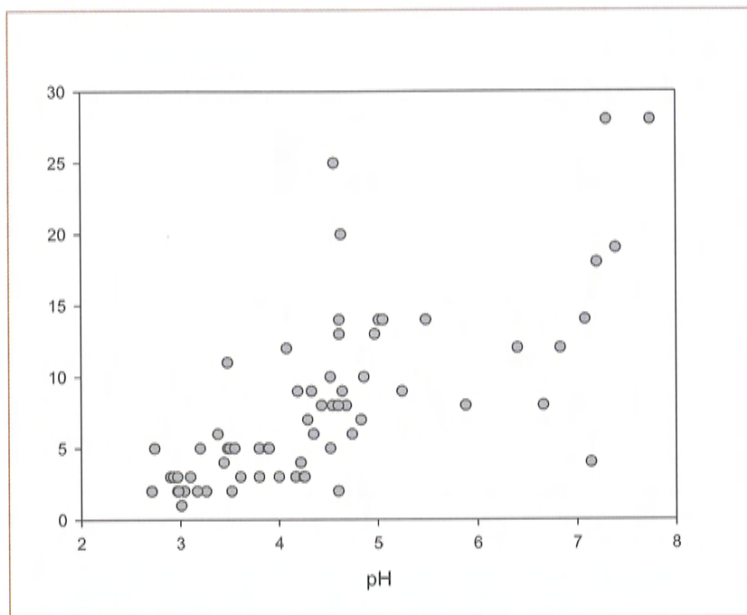


Figure 4 - The diversity of stream invertebrate species is strongly controlled by pH. Low pH streams have very few species.

in acidic waters of pH 3.5 in lab tests. In other cases, invertebrates may be able to survive the effects of mine drainage in short-term tests, but they will not be found in habitats because of limited food or poor habitat caused by metal oxides.

Fish

Native fish in New Zealand, especially from the West Coast of the South Island, can often exist in acidic brown-water streams caused by naturally occurring organic acids. These fish also may be found in moderately acidic (pH 4–6) streams influenced by mining. However, the most acidic streams, with pH less than 4 because of mine drainage, usually have no fish. Some species, including trout, may

be more sensitive to low pH or dissolved metals than natives.

Many New Zealand fish need to migrate to the sea to complete their life cycle. However, some species may not be found in some

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upper tributaries of larger rivers because of barriers to their movements. Physical barriers, such as waterfalls, can prevent native fish and trout from reaching upstream areas of rivers. In a few areas, poor water quality from mine drainage may create a "chemical barrier" that limits fish movement as well.

"In addition to low pH, mine drainage often contains high concentrations of metals, which can include iron, aluminium, manganese, zinc, nickel, copper, arsenic, and others."

Summary

Mine drainage exerts three main stressors on stream biota. Low pH and high concentrations of dissolved metals can be lethal to animals in toxicity tests in the lab, and correspond to species-poor communities in streams. Surprisingly, many algae and microbes appear tolerant of these stressful conditions. The role of metal oxide precipitation is less clear, but it appears to limit all types of biota in streams where the rate of metal oxide accumulation is high. This effect highlights an interesting pattern where water chemistry may not be extreme enough to kill organisms such as invertebrates, but more subtle effects from chronic exposure can affect long-term survival of life in some streams.

Our understanding of how mine drainage affects the ecology of streams is very important when it comes to trying to restore or remediate these systems. Rehabilitation of streams affected by mine drainage can involve several general approaches. First, we can try to prevent the acid mine drainage from forming in the first place by minimising the chemical reactions discussed above. Capping tailings and overburden with barriers can prevent the oxidation of pyrite minerals and has worked well overseas. Another option is to treat the mine drainage prior to its seepage into streams. Both active and passive treatment options are currently being tested in New Zealand. However, it is challenging for treatment systems to deal with all three stressors from mine drainage, and the systems need to function effectively for many years given the continuing generation of impacted water from mines.

Given the importance of coal mining to the New Zealand economy and the significant impacts this activity can have on the environment, the challenge remains for New Zealand scientists to improve our understanding of the impacts of mining on streams. We need to develop new and better tools and models to understand and minimise the potential stressors that can affect stream life. This knowledge can enable mining to continue in an environmentally sustainable manner.

Acknowledgements

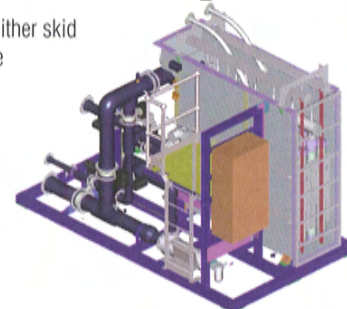
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