A framework to assist decision making on mine drainage related environmental issues in New Zealand.

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ABSTRACT

In New Zealand, water quality environmental issues related to mining are technically challenging, inconsistently regulated, and lack comprehensive local research. A research programme conducted by CRL Energy, Otago University, University of Canterbury and Landcare Research examines geochemical and biological impacts as well as management and remediation aspects of mine drainages on the West Coast of the South Island and in Southland. The main objective of this programme is to provide underpinning research into mine drainage in critical areas that will add consistency and robustness to consent conditions and streamline decision making processes for the mining sector. To achieve this, the geochemical, biological and remediation research will be placed into a publicly available decision making framework document.

In detail this framework document will incorporate:

- Geochemical information that influences mine drainage chemistry
- Interpretation of regional trends and prediction of mine drainage chemistry
- Information on sampling strategies, sample density and analysis methods for mine drainage prediction and management.
- Effects based ecological impact thresholds
- Information on sampling strategies and methods for biological impact assessment
- Review of waste management strategies for overburden
- Optimal selection of active and passive treatment systems

Completion of this project will provide valuable background information for the New Zealand mining sector. In addition, this data will be provided in a format that is easily accessible and applicable to decision making processes that impact on the mining sector.

Additional Keywords: Acid Mine Drainage (AMD), Acid Rock Drainage (ARD), Neutral Mine Drainage (NMD), trace element, macro-invertebrate, biological impact threshold, passive system, remediation, active system, management strategy, framework.

INTRODUCTION

In New Zealand, the effect of contaminated mine drainage on biota in downstream environments is well documented (Barnden, 2005; Barnden and Harding, 2005; Bray et al., 2006; Harding, 2006; O'Halloran et al., 2008). However, in New Zealand, the problems related to uncontrolled discharges from historic mining have not been effectively used to regulate current mines or plan future mining in a robust or consistent manner. The main output of our research is a framework document that will provide consistency, robustness and streamlining to decision making for the mining industry in New Zealand. Our framework document integrates applied research into characteristics and controls of mine drainage chemistry, biological surveys in mining impacted environments, eco-toxicity information and best practise management and remediation technology. In this document we present a description of the regulatory environment in New Zealand, a selection of the datasets we have collected and details of the framework document we are currently compiling.

End users for the framework document include mining companies, exploration companies, regulatory bodies, government agencies, minerals industry associations, universities and the New Zealand public. The framework document will provide background information, bibliographic information, optimal data collection strategies and information for decision making related to the environmental consequences of mine development on aquatic systems. Specifically, the programme aims to:

1. Provide a consistent and streamlined progression of steps to assist with data collection, interpretation and decision making on mine drainage issues during access negotiations and consenting processes.
2. Provide predictive tools to
    a. identify areas where mine drainage contaminants are likely to be released
    b. identify likely ecological impacts
3. Assist consultation between the mining industry, regulators and other stakeholders through the provision of guidelines for determining potential environmental outcomes or impacts arising from mining and providing optimal strategies for management or remediation.
4. To sustain and improve the surrounding environment during the development of new and existing mineral deposits.
5. Raise the public profile of good mining practices to create a more positive image of mining in the community.

THE NEW ZEALAND REGULATORY REGIME.

In New Zealand the regulation of water quality is effect(s) based, and in theory, there are no universal water quality standards for regulation. Ideally, the ecological impact (effect) of contaminants is assessed on a site specific basis and a concentration for each contaminant is established so that negligible or acceptable impacts (effects) occur. Currently, water quality consent decisions and discharge criteria related to mining are made by Regional Councils. This process usually involves consultation with mining company representatives and landholders, including private entities and government agencies that administer land such as the NZ Department of Conservation. There is scope for this process to include public notification and public submissions and in the event that disputes arise decisions are made by the NZ Environment Court.

Mining consent conditions usually include threshold or limiting chemical concentrations for compliance point monitoring, however, these concentrations should relate back to site specific aquatic ecological impact rather than universally applied values. The main advantage of this approach is flexibility to deal with diverse geochemistry in New Zealand, for example geothermal enrichment of trace elements in streams and rivers (McLaren and Kim, 1995; Pope et al., 2005) or naturally acidic streams (Stenzel and Herrmann, 1990) or sites where there is historic contamination including mine drainage. The main disadvantage of this approach is that the database of appropriate ecotoxicity information available is small because New Zealand has many endemic fauna.

In New Zealand, there is a comprehensive document on discharge water quality and protection of aquatic ecosystems (ANZECC, 2000). This document allows freedom for effects based regulations but also includes a set of very conservative water quality recommendations for protection of aquatic ecosystems based on extensive search of international peer reviewed ecotoxicity data. Many of these conservative values do not readily apply to New Zealands mineral rich areas where trace elements and acid are naturally present at low, but significant concentrations (Boothroyd et al., 2006; Fitzpatrick et al., 2008; Haffert and Craw, 2008; Haffert et al., 2006; Pope et al., 2006a, b; Pope et al., 2008).

The objective of our applied research is to identify a scientifically robust but streamlined method of determining effects based consent criteria for areas that are to be disturbed by mining within two mineral rich provinces in New Zealand, Southland and West Coast. This research will prevent over regulation of the minerals industry and protect the natural New Zealand geo- and bio-diversity.

WEST COAST MINE DRAINAGE CHEMISTRY

Coal Mine Drainage Chemistry

In New Zealand, there are a limited number of different groups of rocks that host mineral or coal deposits. For example, there is only one group of rocks that host substantial hard-rock metal (gold) mining (Greenland Group metasediments) in the West Coast Province of New Zealand and there are only two sedimentary formations (Brunner Coal Measures (BCM) and Paparoa Coal Measures (PCM)) (Nathan et al., 2002) that host significant coal mining in this province (Figure 1). It is therefore possible to characterise rocks and understand the variability of mine drainage chemistry at a regional level and it is also possible to predict mine drainage chemistry and identify areas where mining is likely to cause downstream water quality problems.

To characterise and understand coal mine drainage chemistry we have collected mine drainage samples from current and historic mines and rock samples for acid base accounting analysis. Acidity plots of coal mine drainage samples are bimodal (Figure 2) reflecting the two sets of coal measures (Pope et al., submitted). Mines in Paparoa Coal Measures release little acid whereas mines in Brunner Coal Measures produce very acidic mine drainage. Acid base accounting analyses are also bimodal and supporting the bimodal results of AMD samples (Pope et al., 2006a). Review of the depositional environment for the coal measures sequences indicate that Paparoa Coal Measures deposited in a fluvial environment with no influence from sulphate rich marine water and rocks. Brunner Coal Measures deposited in an estuarine environment with substantial marine (sulphate rich) influence during deposition and post deposition in overlying rocks (Nathan et al., 2002; Newman and Newman, 1992; Suggate, 1959).

Brunner Coal Measures mine drainage also differs between underground and opencast mines. Underground mines produce mine drainage that is relatively Fe rich and opencast mines produce mine drainage that is relatively Al rich (Figure 3).

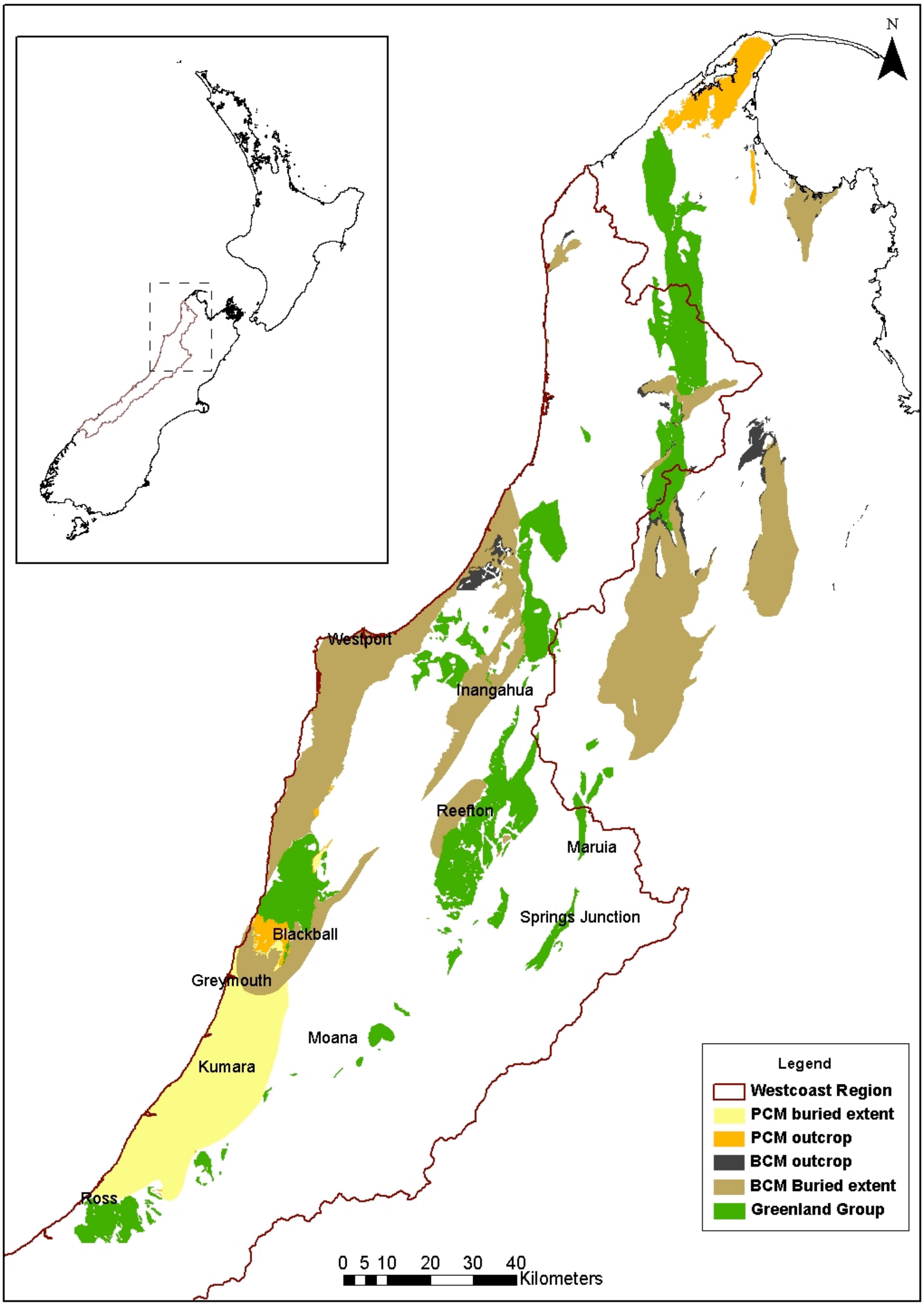

Figure 1: Geology of the West Coast province showing Brunner Coal Measures (BCM) Paparoa Coal Measures (PCM) and Greenland Group meta sediments.

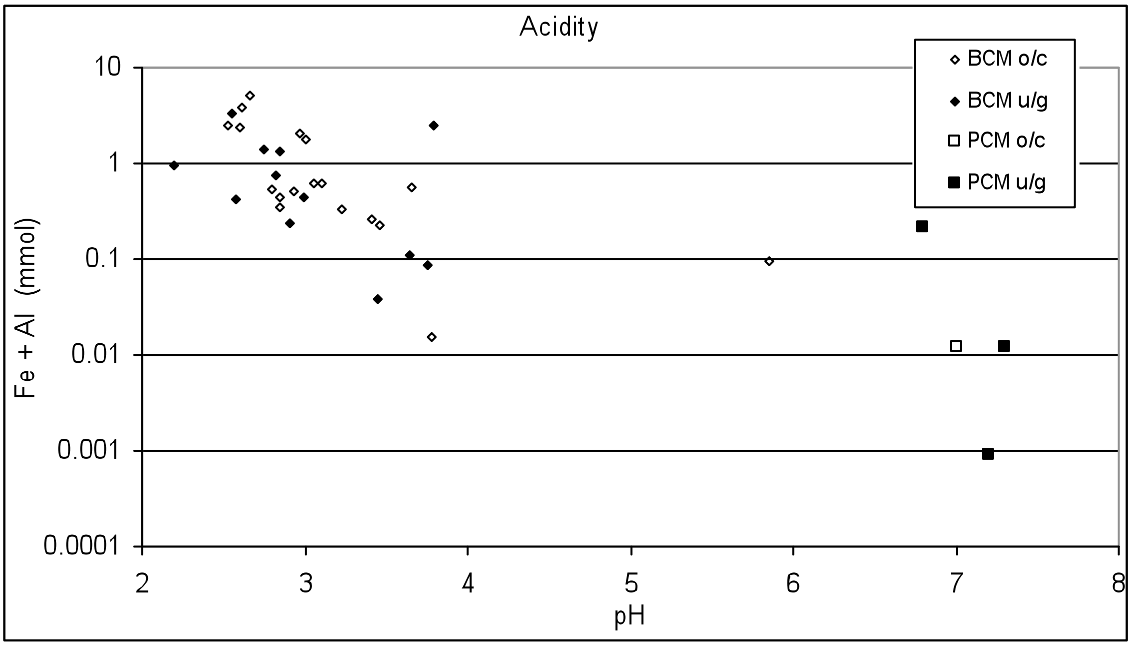

Figure 2: Acidity of Brunner Coal Measures (BCM) and Paparoa Coal Measures (PCM) for underground (u/g) and open cut (o/c) mines.

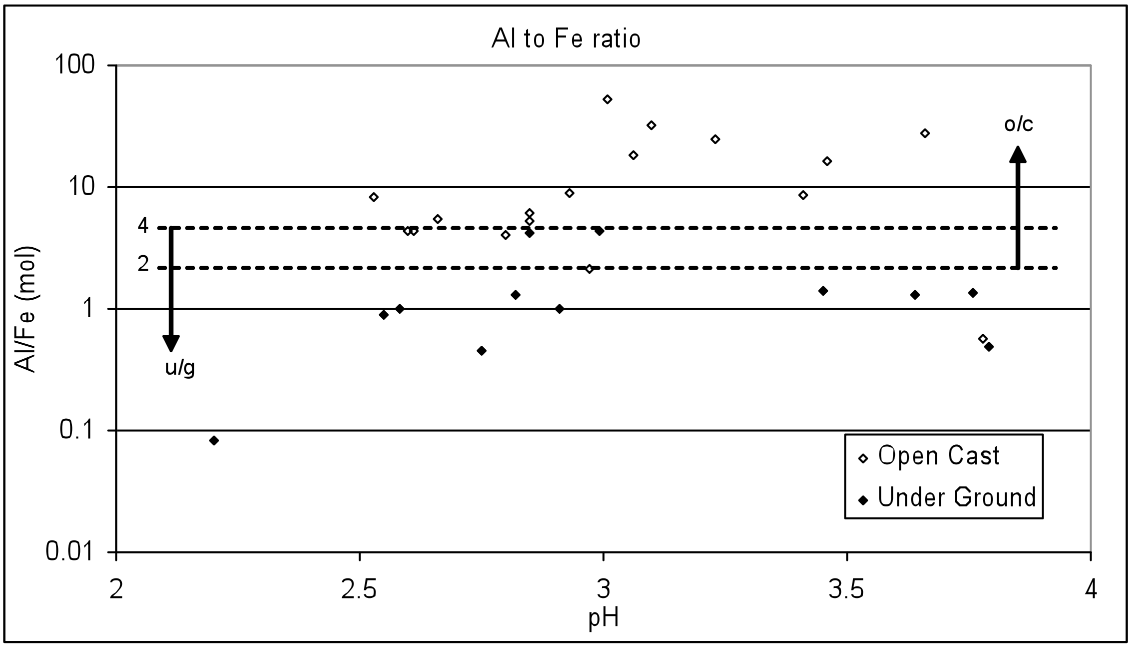

Figure 3: Aluminium to iron ratio in BCM mine drainage. Underground (u/g) mines are all lower than 4 and opencast (o/c) mines are almost all greater than 2.

Trends in mine drainage chemistry relating to specific rock types within the coal measures sequence and hydrogeological conditions in mine drainage source rocks can also be identified (Pope et al., 2006a, b). Brunner coal measures mine drainage is usually Zn and Ni rich and these trace elements occur at elevated concentrations in pyrite in the coal measures sequence. (de Joux and Moore, 2005; Weber et al., 2006).

Gold Mine Drainage Chemistry

Gold mine drainage chemistry in the West Coast area is often enriched in As but typically has circum-neutral pH and excess HCO_3 buffering. Arsenic concentrations in drainages from mine impacted sites are limited by scorodite ($FeAsO4 \cdot 2H2O$) and sometimes arsenolite (As_2O_3 – a product of historic sulphide roasting) and therefore can be very high >50ppm (Haffert and Craw, 2008; Haffert et al., 2006, submitted). However often As rich drainages from mining impacted sites are partially attenuated by adsorption onto Fe oxy-hydroxide minerals very close to discharge points. The effectiveness of As attenuation depends on the concentration of As and the availability of Fe(II) in the mine drainage discharge area. Current large scale mining employs active treatment specifically to remove As. In general, As contributed to the environment by mining in the West Coast province is relatively small compared to natural weathering of As rich rocks and there is an elevated background As concentration in many West Coast streams (Haffert and Craw, 2008; Haffert et al., 2006; Hewlett et al., 2005; Noble et al., 2002).

Geochemical Information in our Framework Document

The framework includes background information and recommendations as a start point for mine drainage consent decisions. Our framework document is not prescriptive because there are many site specific factors where the approach to assessment of mine drainage chemistry should be customised. Thus, instead of prescribing a regime of sampling and analysis, the document provides background information to guide the user through decisions regarding data acquisition and interpretation.

Specifically, the framework document includes:

- Background geological information that impacts on mine drainage chemistry.
- Interpretation of geochemical information and implications for mine drainage chemistry at a regional scale
- Recommendations for rock analysis methods to predict mine drainage chemistry
    - Application of different analysis methods
    - Discussion and interpretation of results
    - Limitations of methods and pitfalls in interpretation
    - References related to different methods
- Rock sampling strategies and guidelines for sample density
- An approach to prediction of mine drainage chemistry at a proposed mine based on analysis of historic and current mine drainage chemistry (Pope et al., 2006a)
- Discussion of site specific factors that influence prediction of stream chemistry at consent points
- Introduction and references to reactive transport modelling.

Provision of this information in the framework document will provide a basis for negotiation of access or consent details between mining companies and other stake holders. The information provided will assist users to identify appropriate suites and quantities of information to predict mine drainage chemistry and downstream water quality.

ECOLOGICAL IMPACT ASSESSMENT

Ecological effects of mine drainage on flora and fauna are complex and inter-related and vary between sites. Often water quality consent conditions are based on the use of conservative values from prescriptive guideline documents such as (ANZECC, 2000), or wider literature review. But this does not take into account the relatively unique fauna of New Zealand. For example, between 90 to 95% of the approximately 670 species of benthic invertebrates described in New Zealand are endemic and most native fish are also endemic. As such, fundamental research on the impacts of mine drainage on New Zealand aquatic species is required.

To produce effects based ecological impact information the interaction of water and the food web must be studied (Barnden and Harding, 2005; Bray et al., 2006; Harding, 2005; Niyogi and Harding, 2007). Our research examines the chemical and physical impacts of mine drainage on multiple aquatic trophic levels including bacteria and algae, macro-invertebrates, and fish. Study methods include sampling the diversity and abundance in mine impacted drainages, in-stream experiments of biological activity and recovery in mine impacted drainages and 96hr mortality ecotoxicity testing (O'Halloran et al., 2008). Some New Zealand flora and fauna adapted to chemical conditions that fall well outside common regulatory guideline values and some are able tolerate elevated trace element concentrations and moderately acidic conditions. Therefore, overuse of conservative regulatory guidelines will bias New Zealand toward one particular type of aquatic ecosystem.

Our research also demonstrates that the results of common biological effects testing such as 96hr mortality testing is dependant on the chemical conditions of the site at which species for testing are collected (Figure 4). If the individuals to be tested by 96hr mortality test are collected from relatively acidic natural conditions (~pH 5) they survive more acidic conditions during testing than the same species collected from neutral pH conditions (O'Halloran et al., 2008).

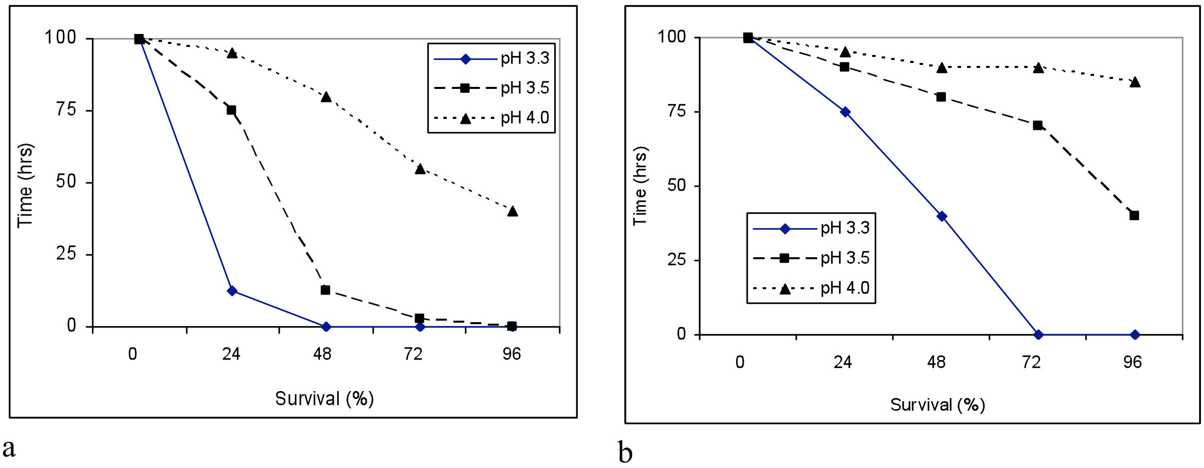

Figure 4: a) Survival of macro invertebrates sourced from pH 7.4 stream in pH 3.3, 3.5 and 4.0. b) Survival of macro invertebrates sourced from pH 5.7 stream in pH 3.3, 3.5 and 4.0.

Data from ecological field surveys and experiments are used to predict ecological impact in a general sense. Stream pH and element concentrations are used to identify one of 6 broad levels of impact that relate to a general set of outcomes for the aquatic ecosystem (Figure 5). Detailed interpretation of outcomes for a specific site requires site specific information on the stream chemistry. Our data to date indicate that in some areas it is possible to have moderately acidic pH (4-6) and elevated concentrations (up to about 1ppm) of any of the common metals in West Coast province mine drainage (Fe, Al, Ni, Zn or As) with negligible impact on stream ecology. Field surveys and ecotoxicity experiments to refine and improve this broad classification of impact are underway.

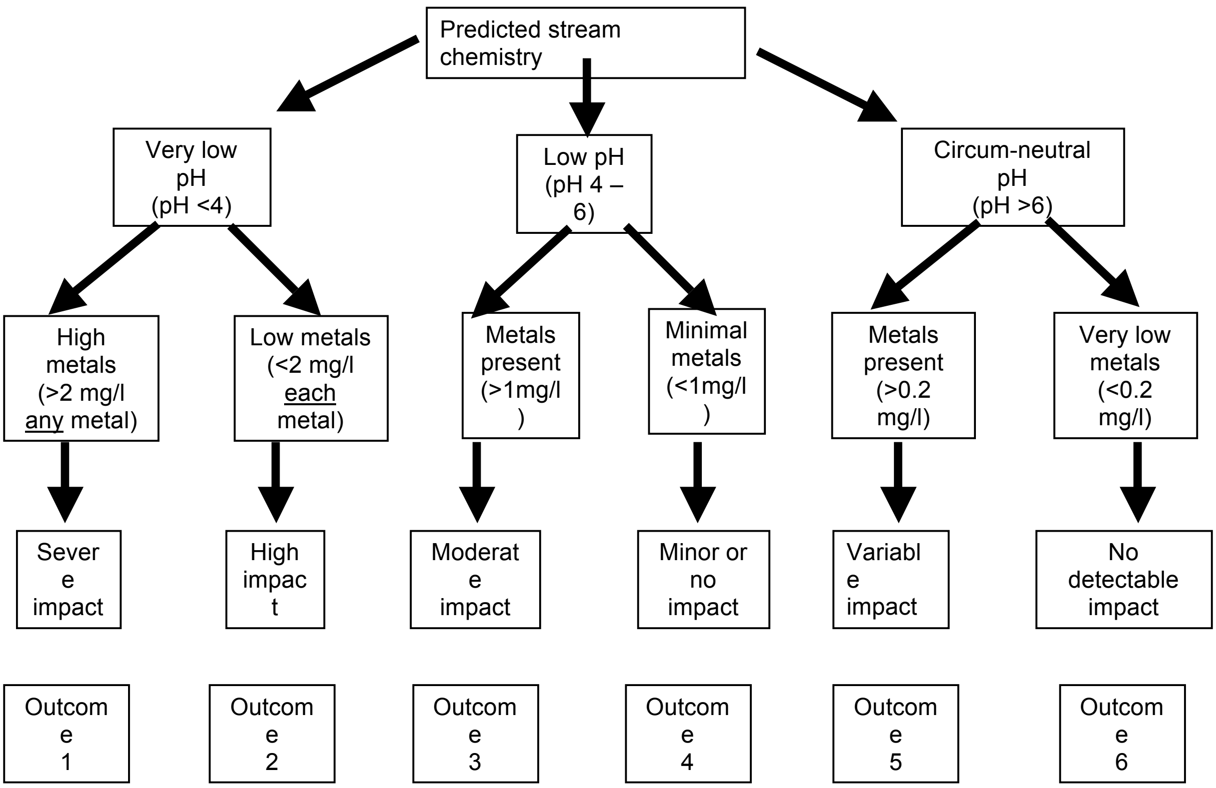

Figure 5: Preliminary ecological impact model for West Coast streams, South Island. Metals included to date include Fe and Al and preliminary results for Zn, As, and Ni.

Ecological information in the framework document

In the framework document, each of the outcome boxes (Figure 5) has a description that summarises aquatic ecological impacts such as; effects on species abundance and diversity, truncation of the food web, disruption to processing by low trophic level biota such as bacteria and fungi, establishment of tolerant monocultures and potential for disruption to life cycles. The level of impact described for each outcome provides a general start point for establishing effects based water quality criteria on a site specific basis. At the site specific scale the aquatic flora and fauna will vary, however, the functionality of the food web is likely to be disrupted in similar manner by contamination to the six different levels described.

The framework document provides information on methods to assess ecological impact and bibliographic information that is strictly relevant to New Zealands largely endemic flora and fauna.

MANAGEMENT AND REMEDIATION

Management strategies to mitigate mine drainage from waste rock and tailings are diverse, complex and site specific but include strategies such as water management, isolation of potentially acid-forming material, and capping of waste rock or tailings piles. In the framework management techniques to minimise acid formation or release of trace elements are reviewed and the applicability to conditions in New Zealand are considered. For example, some management techniques are only applicable if rainfall is low and these are inappropriate on the West Coast of the South Island, which typically has very high annual rainfall (up to 6m per year).

Remediation strategies for mine drainage can be separated into two categories, active and passive. Deciding between the two approaches incorporates many factors such as cost, availability of electricity and manpower, space, flow volumes and chemistry. However, in general active treatment systems are most suitable for operational mine sites where conditions change during mine life and electricity and manpower are readily available whereas passive systems can be emplaced at both operational and non-operational sites. Active treatment systems are usually constructed in an engineered and 'off the shelf' manner with well established, modular components (Trumm, 2008). Passive treatment systems are selected based on a complex array of parameters including, space available, pH, oxidation state, concentration of Fe(II), Fe(III), Al, As and dissolved oxygen (Trumm, 2007). Details on selection of remediation systems for New Zealand conditions are summarised within flow charts in this volume (Trumm, 2009).

Passive treatment systems are best optimised to site conditions with small scale field trials (Trumm, 2005, 2006) and usually require a low level of maintenance and monitoring. Our research into passive systems includes analysis of the performance of scaled down versions of the systems under filed and laboratory conditions.

Remediation and management in the framework
The framework provides flow diagrams to assist in selection of management and remediation techniques (Trumm, 2007, 2008). The framework also provides information on small scale trials that can be completed to assess the suitability and performance of treatment systems. Background information including construction details, operational considerations, costs, longevity, and limitations are included in the framework.

Passive treatment systems for acid mine drainage from coal mines have been the focus of research to date. However, arsenic contamination from historic hard rock gold mining is also present on the West Coast of the South Island (Haffert and Craw, 2005, 2008; Hewlett and Craw, 2003; Hewlett et al., 2005; Noble et al., 2002). Passive treatment for arsenic rich mine drainage is the focus of current and future research (Rait et al., in prep).

SUMMARY
In New Zealand, the minerals industry is regulated by an effects based system. This system has the advantage of flexibility to deal with New Zealands geo and bio-diversity, however, often ecological effects are poorly understood or researched because New Zealand species are often endemic. Our research demonstrates that effects based regulation is more appropriate than conservative universal guidelines for the New Zealand situation because mine drainages that contain relatively high concentrations of trace elements and moderately acidic pH can occur with negligible ecological impact. The purpose of our research is to provide robust applied science in three fields to underpin data collection and decision making relating to mine consents for the West Coast and Southland mineral provinces in New Zealand. The three fields in which we provide research are

- Characterisation and prediction of mine drainage chemistry
- Identification and quantification of ecological effects of mine drainage
- Selection and optimisation of mine drainage prevention, management and remediation strategies.

Our research will produce a framework document that will be a useful resource to exploration companies, mining companies, consulting organisations, local government, regional government and the New Zealand public.

ACKNOWLEDGEMENTS

This research is funded by the Foundation for Research Science and Technology under contract FRST CRLX401 – Delivering pathways to mineral wealth. Important support for this programme is provided by several organizations including, the West Coast Regional Council, Environment Southland, DoC, Solid Energy New Zealand, Oceana Gold, Francis Mining, New Zealand Coal Association and Minerals West Coast. Special contributions to this research programme have been made by several students at Otago University and University of Canterbury. Amanda Black and Kathryn O'Halloran have previously contributed to this research project.

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