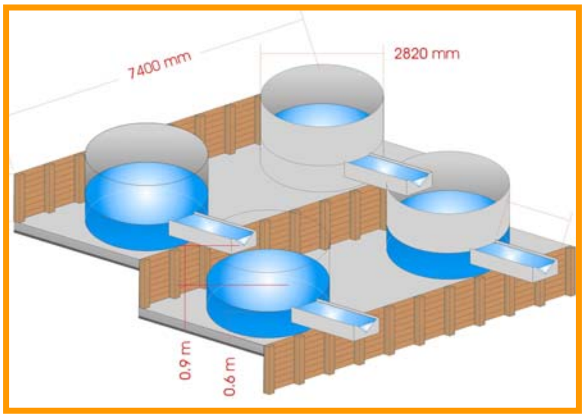
West Coast and Southland Mine Drainage Workshop II

July 2008



CRL Energy Ltd

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1 Overview

Welcome to the West Coast and Southland Mine Drainage Workshop.

The material presented over the next day and a half is from a research programme funded by the NZ Foundation for Research Science and Technology (CRLX0401). This is a 6 year research programme completed by scientists from CRL Energy, Canterbury University, Landcare Research and Otago University; currently we're at the start of year 5.

The purpose of the research programme is to develop a framework to assist data collection and decision making related to mine development proposals. The framework document will assist mining companies, regulatory agencies and other parties to assess 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 relating to access and consenting processes.

2. To sustain and improve the surrounding environment during the development of new and existing mineral deposits.

3. Develop a set of standard guidelines for regulators and industry to provide greater certainty in environmental outcomes arising from mining activities.

4. Assist consultation between the mining industry, regulators and other end users through the provision of guidelines for determining potential environmental impacts arising from mining.

5. Raise the public profile of good mining practices to create a more positive image of mining in the community.

Within the program we are conducting research into mine drainage geochemistry, ecological impact, as well as management and rehabilitation. The programme is overseen by a Governance Panel with representatives from mining companies, industry organisations, regional councils and Department of Conservation (DoC).

We present our research findings on a 6 monthly basis to the governance panel and through other media such as conferences, journals, books and posters. Publications from this research can be found at:

http://www.crl.co.nz/research/mine_drainage.asp

The main output from our research programme will be a framework to predict mine drainage chemistry, identify potential ecological impact and enable selection of optimal management or remediation techniques as required. In the first part of this workshop we will be presenting our first draft of the Framework Document, and demonstrate the application of the framework using a case study. Your feedback on our framework is appreciated. In the second part of the workshop we will present the results from on-going research which underpins the development of the framework.

2 Programme

Thursday

8:30 – 8:45	*Assemble – coffee*
8:45 – 9:00	Introduction and Research Programme Overview J. Pope
9:00 – 9:25	Framework overview and application J. Cavanagh
9:25 – 10:15	Prediction of water quality impacts J. Pope, D. Craw, & L. Haffert
10:15 – 10:30	*Morning Tea*
10:30 – 11:20	Prediction of ecological impacts J. Harding, O. Champeau, & D. Niyogi
11:20 - 12:15	Choosing management and remediation systems D. Trumm, R. Buxton & R. Rait
12:15 – 12:40	Macraes gold mine environmental management and monitoring Guest Speaker - John Bywater, Oceana Gold
12:40 – 1:30	*Cut Lunch Provided - Transport to field site*
1:30 – 4:30	Field trip / Practical exercise (weather dependent). Bellvue mine site • data collection • water quality prediction • ecological impact prediction • management and rehabilitation planning
4:30 – 5:30	*Transport to Greymouth*
6:00 – 7:30	*Drinks and Nibbles (Kingsgate Hotel)*

Friday

8:30 – 8:45	*Assemble – coffee*
8:45 – 9:30	Mine drainage in Southland J. Pope, D. Craw & T. Mulliner Arsenic Discharge at Waiuta L. Haffert & D. Craw
9:30 – 10:15	Progress on assessing ecological impacts J. Harding, D. O. Champeau & D. Niyogi
10:15 – 10:40	*Morning Tea*
10:40 – 11:30	Arsenic remediation and Herbert Stream remediation D. Trumm & R. Rait
11:30 – 12:00	Back to the framework – wrap up discussion J. Cavanagh

3 Framework Presentations

3.1 Framework overview and application

A framework to assist with decision making and planning future mine developments on the West Coast and Southland is currently being developed. The framework focuses on prevention or minimisation of detrimental impacts on aquatic environments and draws together the different strands of research including:

- geochemistry of rocks and streams in mined areas
- biological information from aquatic systems downstream of mines
- aquatic toxicity of mine drainage
- remediation and rehabilitation

It is intended that the framework will provide consistency and transparency in decision-making related to establishing water quality targets for proposed mine operations. Specifically, it is viewed that the information provided in the framework will assist with regulatory requirements such as access arrangements, and resource consents. The framework may also be useful in developing future regional plans for water quality. In addition the framework will present the research in a way that may be applied by other end-users such as industry, local councils, central government agencies (e.g. DoC), community and iwi.

The framework comprises a flow chart outlining a series of decision points. Decision support is provided by recommending data collection (e.g. rock geochemistry, mine type) and assisting with data interpretation. Information collected is related to a likely ecological impact supposing a mine development proceeds and can be used to select optimal management or remediation options should environmental impact be ‘unacceptable’. This information may also be used to manage existing mining operations, or select appropriate remediation options for historic mining operations.

The framework does not establish ‘acceptable’ and ‘unacceptable’ water quality criteria because these are likely to be different at different sites and because there are social, economic and cultural factors that may also influence decision-making. Instead the framework provides a robust scientific basis to determine the level of impact on aquatic systems and this decision is to be made by end-users during consultation on a proposed mining operation.

3.2 Prediction of water quality impacts

Prediction of mine drainage chemistry and downstream water quality at proposed mine sites can be undertaken using different types of information. Indicative information on mine drainage quality can be collected by desktop study of reports, books, conference proceedings and journal articles. In particular, information on the target commodity, region, and geological formation is required. Acid-forming potential and trace element content of rocks to be disturbed by mining are often the key environmental considerations for both coal and gold mines. Quantitative assessment of the acid forming potential of rocks to be disturbed by mining requires sample collection and acid base accounting analysis. More detailed information on mine drainage chemistry and trace element content can be obtained using XRF analysis and a variety of long term leaching simulation tests.

Once mine drainage chemistry is predicted with the appropriate level of certainty, site specific hydro-geological information and background water quality information is required to predict downstream water quality. Hydrological data, background water quality and predicted mine drainage chemistry should be integrated using a reactive transport approach rather than a simple dilution model. Reactive transport modelling incorporates dilution with buffering of pH by natural sources of bicarbonate or precipitation of hydroxides as well as other reactions that occur during mixing mine drainage with surface water.

Arsenic is the main environmental issue associated with hard-rock gold mines, and acidity is almost invariably controlled by surrounding rocks to pH 7-8. Typical gold mine ore contains about 2000 times as much arsenic (as arsenopyrite, FeAsS) as gold. The gold and arsenic are closely interlinked in the ore rocks, so that all gold-extraction techniques affect the arsenopyrite as well. The arsenopyrite will dissolve in water during all mining and processing activity. Rainwater runoff from the mine excavations where ore is exposed will have significant dissolved arsenic, whereas waste rocks have little arsenopyrite and dissolved arsenic in runoff is less of an issue. Mineral processing involves agitation of crushed ore for several hours, so processing waters have high dissolved arsenic. Mine tailings are deposited as a slurry with arsenic-bearing processing water, and any arsenic minerals in the tailings can dissolve over time to increase the amount of dissolved arsenic.

All of the above aspects of gold mining expose arsenopyrite to oxidation. The maximum dissolved arsenic concentration in waters is controlled by the oxidised arsenic mineral scorodite ($FeAsO_4.2H_2O$). When the dissolved arsenic concentration reaches the scorodite solubility concentration for a given pH, scorodite will precipitate, and the dissolved arsenic concentration will not go higher than this level. Hence, scorodite solubility provides a useful predictor for maximum expected dissolved arsenic concentration at a site. Scorodite solubility increases with increasing pH, so minor acidification of mine waters is desirable, and addition of lime (as in AMD settings) is undesirable. Dilution of mine waters ensures that real values for dissolved arsenic concentrations are generally lower than scorodite solubility. Extraction of arsenic from water before discharge is often necessary.

3.3 Predictions of ecological impacts

A healthy stream ecosystem usually includes a range of species of plants and animals which feed, prey and depend on each other in a number of ways (Fig. 1). At the base of most stream foodwebs are plants (primarily algae) and terrestrial matter (e.g. leaves and wood) that are then decomposed by bacteria and fungi and eaten by a range of invertebrates (e.g. insects). These invertebrates are the main food for fish and crayfish. Mining discharges can directly and indirectly affect all components of a stream foodweb.

Coal and gold mining in differing geologies may create a range of water chemistry conditions which can have highly variable effects on stream communities and foodwebs.

The most severe conditions are usually associated with acid-forming geologies (PAF – Potentially Acid Forming rocks). These geologies have the potential to produce acidic waters, high in toxic metals (e.g. Fe, Al, Ni, Zn). They may also create metal hydroxide precipitates in streams and create highly turbid waters.

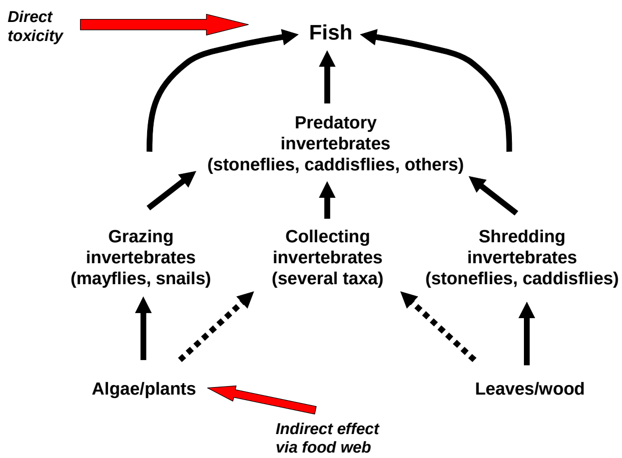

Figure 1: Typical stream food web

Severe impacts (Figure 2) may result in only a few species of acid tolerant algae and invertebrates surviving in a stream and all fish dying. Gold mining is more likely to create sediment and turbidity issues and possibly release metals such as As, Sb & Hg. These metals can be toxic to many animals.

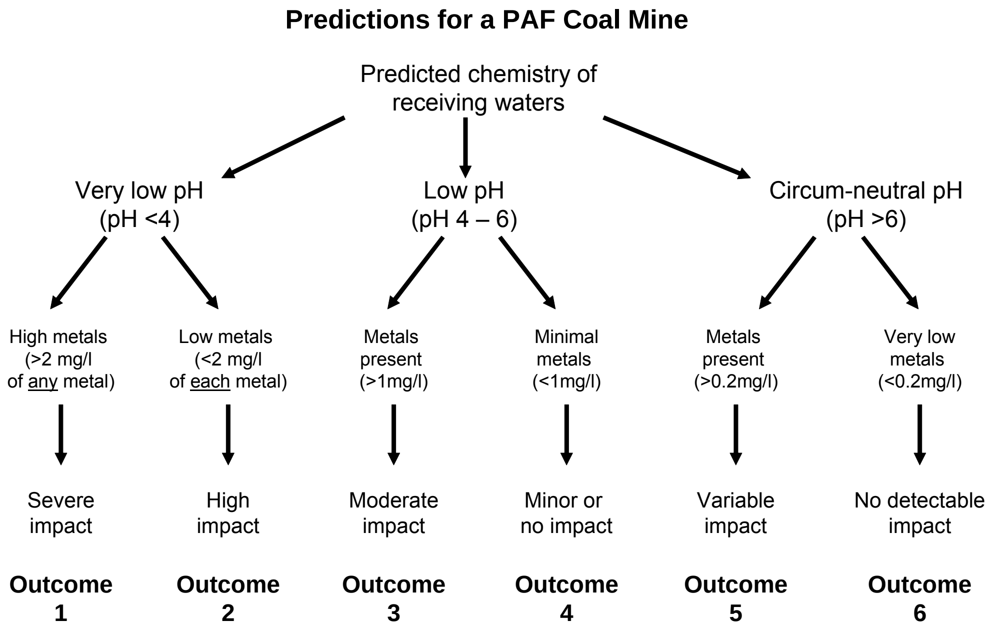

Figure 2: Impact assessment model

3.4 Management and remediation systems

Mine waste management can be a cost-effective means of impact minimisation. Mine waste management goals are to; prevent or reduce the amount of water entering the mined area, reduce the contact of water and/or oxygen with acid-forming materials, and neutralise or reduce the level of contaminants present in any water runoff. To achieve these goals involves evaluation of factors that influence mine drainage at each site, particularly background water quality, the volume, composition of mine waste material, and the position of the overburden and waste rock relative to surface and ground water. Appropriate site-specific management options are then applied to reduce the volume of mine drainage or minimise acidity and trace elements concentrations.

Remediation of mine drainage may be required even with good waste rock management practices. Remediation can be accomplished by either active or passive treatment systems (Figure 3), or a combination of both. Active systems typically require continuous dosing with chemicals, consume power and require regular operation and maintenance, but they are very reliable. Passive systems rely on natural physical, geochemical and biological processes but can fail if not carefully selected and designed. A series of flow charts have been developed throughout this programme and can be used to choose between active and passive treatment and then to select an appropriate system design. Site parameters necessary to use these flow charts include chemistry, flow rate, available land area, availability of power, and type of mine site.

Arsenic is a highly toxic trace element and mobile throughout a range of pH conditions. Arsenic removal can be carried out by a number of processes with variable removal efficiencies. The conventional techniques for arsenic removal include oxidation, coagulation-precipitation, adsorption, ion exchange, membrane/reverse osmosis and biological processes. Oxidation occurs via aeration, chemical oxidation (sodium hypochlorite, ozone, bleach, citric acid and permanganate), electrochemical or photo-catalytic oxidation. Coagulation-precipitation involves co-precipitation of As into an insoluble solid that is precipitated and settled. Chemicals used for co-precipitation include Al and Fe hydroxides, ferric sulphate, ferric chloride and ferrihydrite. Arsenic can be removed by adsorption by activated alumina, iron oxide coated sand, ferrihydrite, zero valent iron and activated carbon. The choice of treatment depends on economics, availability of chemicals or adsorptive media and concentration of arsenic.

Figure 3: Management and rehabilitation active treatment, clarifier (left), passive system (right)

4 Fieldtrip – A Case Study at Bellvue minesite

4.1 Introduction

Bellvue mine was an underground mine (Figure 4 and 5) operational during the 1920s to 1950s. It produced high sulphur coal and is within Brunner Coal Measures.

Today we will be examining a scenario of re-opening the Bellvue Mine as a small open cast operation. This is a hypothetical scenario that we have developed in order to demonstrate how the mine drainage framework could be applied. We have no data on the amount of coal that remains at Bellvue, its quality, optimal mine planning or the economics of the proposed operation. However, this site suits our purposes in illustrating the application of the framework because we have analytical results for mine drainage chemistry and catchment water quality. Additionally, we have drill core and acid base accounting data from Brunner Coal Measures that can be applied to this site.

The Mining Scenario:

During the first phase of mining, we plan to strip cap rock off a quarter of the underground workings, starting at the current mine portal. The purpose of the field trip is to examine:

- What geological and ecological samples might be required and how they could be used to help us predict mine drainage quality.
- Mine drainage from the historic workings and think about the chemical processes as these flow down stream
- What methods are used to assess ecological health of a stream system
- The impact of historic mine drainage on ecology
- Information that is required for optimal management of mine waste
- Identify optimal rehabilitation systems if necessary

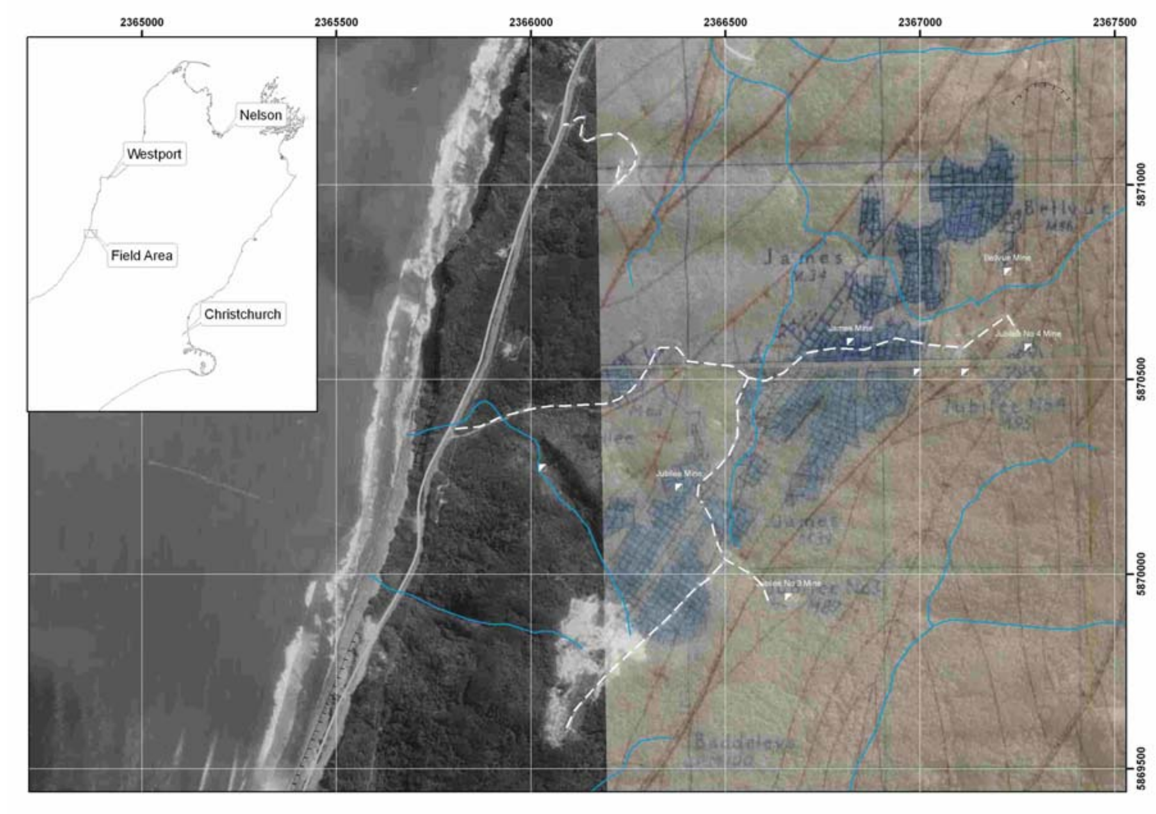

Figure 4: Bellvue workings top left over air photo.

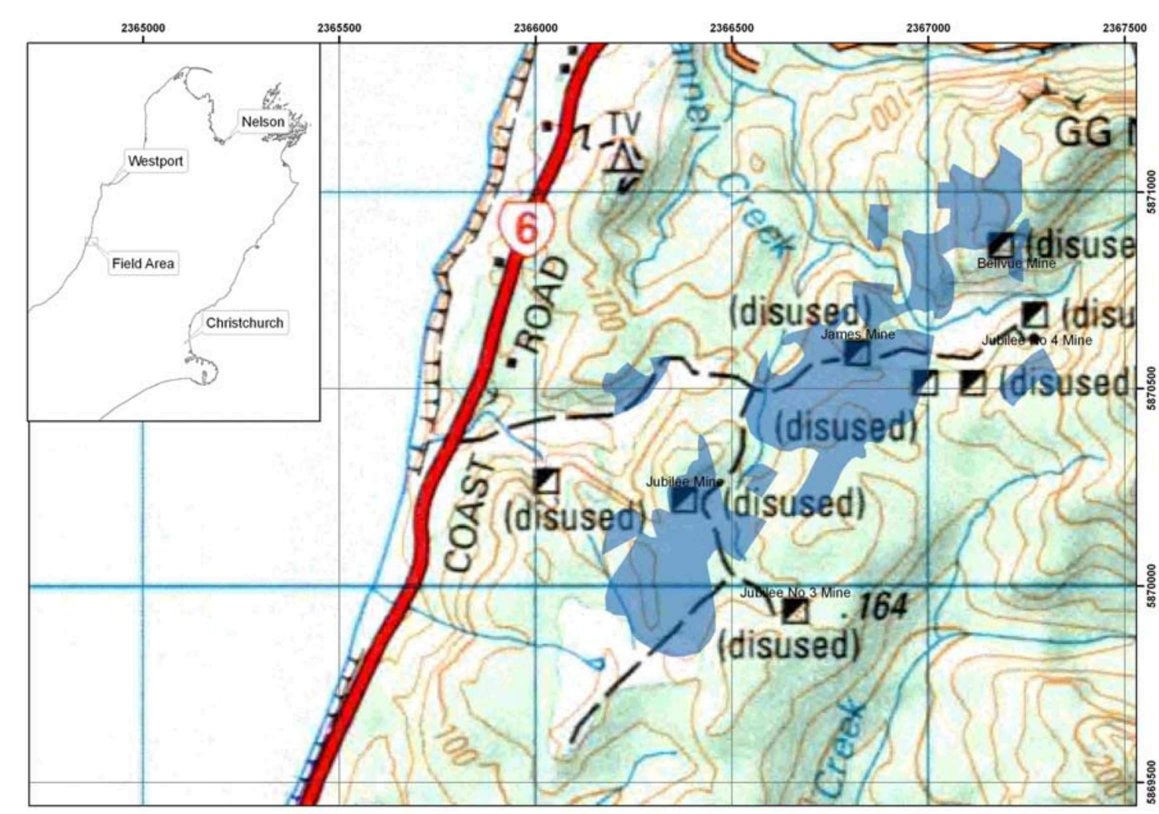

Figure 5: Bellvue workings (top left) over topography

4.2 Water quality prediction

Background data:

Commodity:	Coal
Region:	West Coast
Geological Formation:	Brunner Coal Measures → *Likely PAF rocks present*

Rock analyses and prediction of mine drainage chemistry:

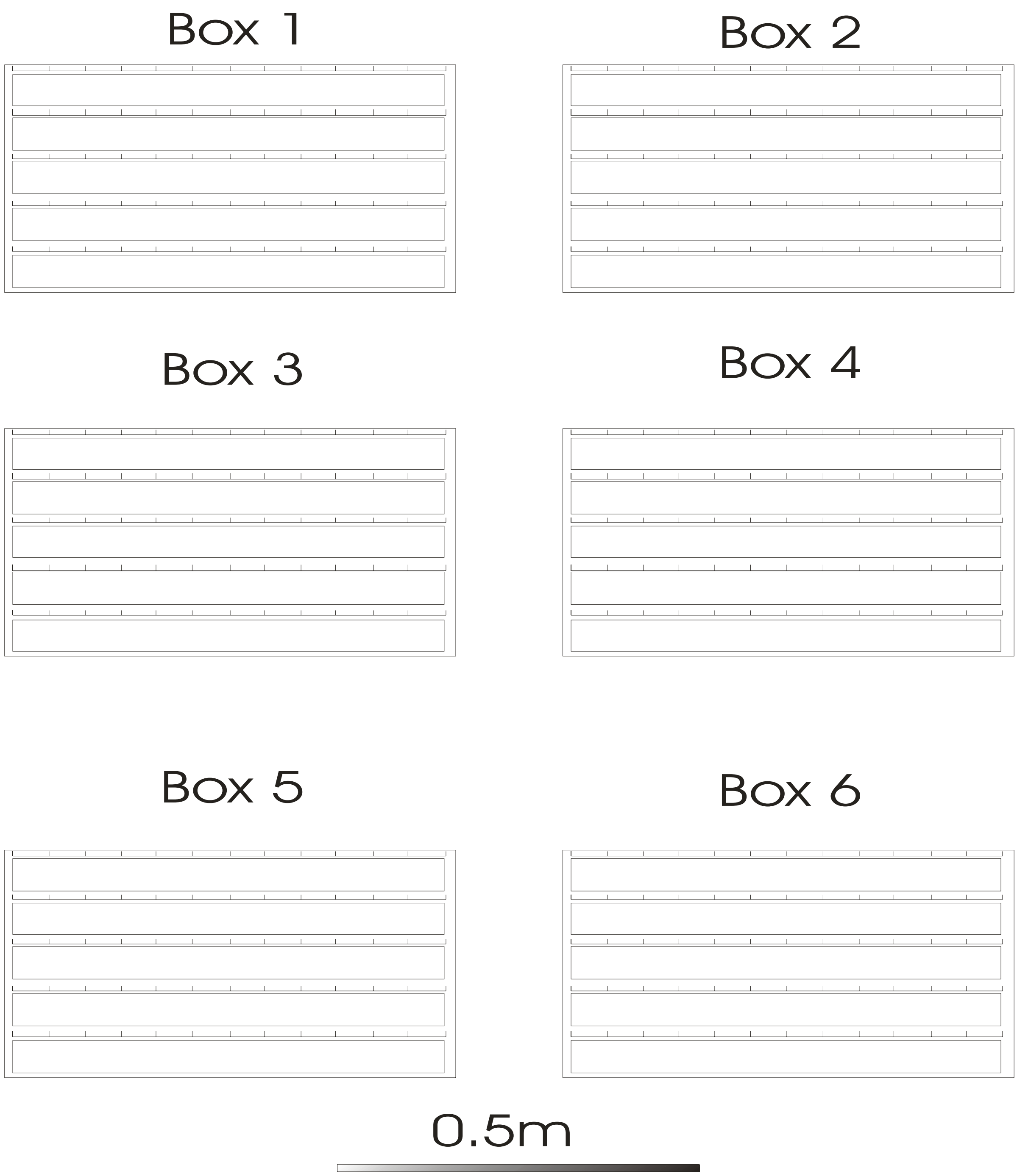

Figure 6: Core Sampling Plan

Results:

Acid base accounting data from these rocks indicates that some sandstones host pyrite and are acid forming.

Use additional information to get prediction of mine drainage chemistry (Figure 7)

Mine Type:	Open Cast
Hydrogeology:	Above water table
Local Geology:	First pass analysis indicates acid forming rocks are sandstones

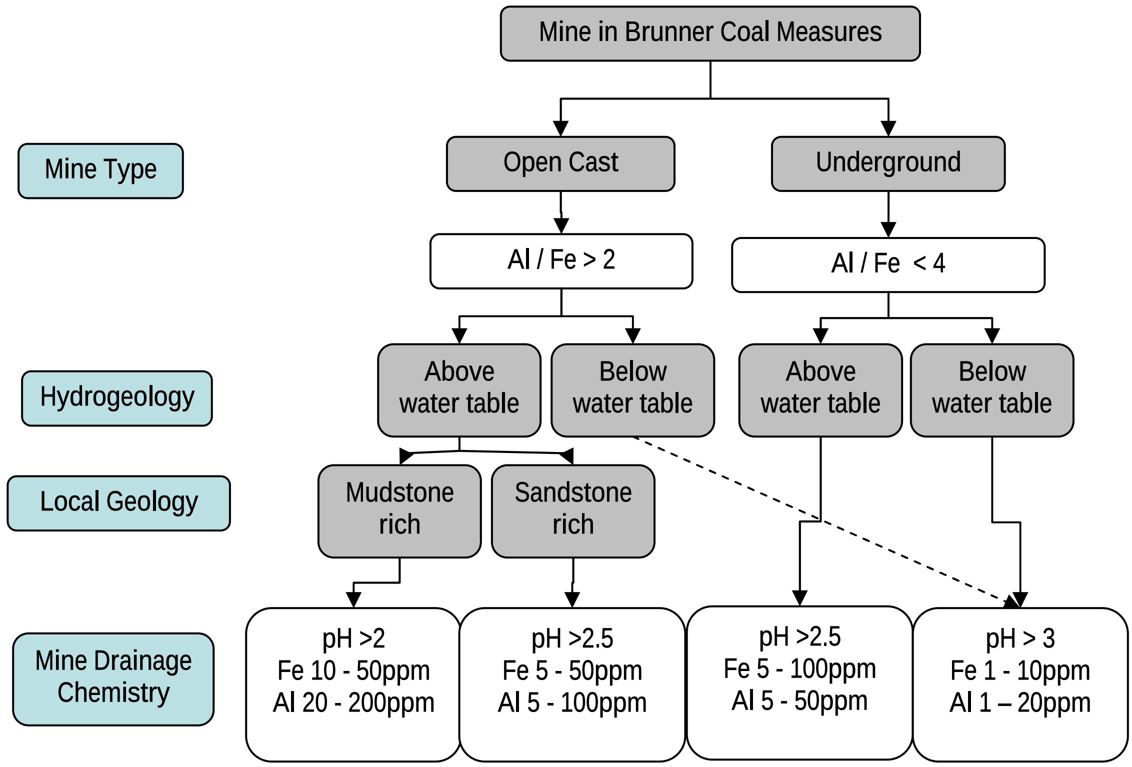

Figure 7: Mine drainage chemistry prediction from Brunner Coal Measures. Dotted line indicates likely result (little data).

How good is this prediction?

- Based on AMD from about 50 mine sites – indicates trends
- Concentrations span a wide range so modelling of mixing AMD with surface water might require sensitivity analysis

Prediction of water quality downstream of the mine:

Additional information:

Flow information:	Current AMD	1.4L/s
	Flow from proposed workings	0.7L/s
	Cannel Ck upstream of Bellvue	12L/s

What kind of samples should we take and why?

Filtered/unfiltered/acidified/non-acidified?

What field parameters to measure, what analyses and why?

Results:

Partial results are presented for two different mixing scenarios (Table 1-3).

Table 1: Current water chemistry

	pH	flow	Al	Fe	HCO_3^-
Belluve AMD	2.6	1.4	50	70	0
Cannel Ck d/s	3.2	14	5.56	7.78	0
Cannel Ck u/s	7.8	12.6	0.3	0.5	0

<u>Mixing Scenarios:</u>

Table 2: Scenario 1 - Add AMD from proposed mine to current AMD

	pH	flow	Al	Fe	HCO_3^-
Belluve AMD	2.6	2	70	50	0
Cannel Ck d/s	3.1	14	11.11	7.94	0
Cannel Ck u/s	7.8	12.6	0.3	0.5	0

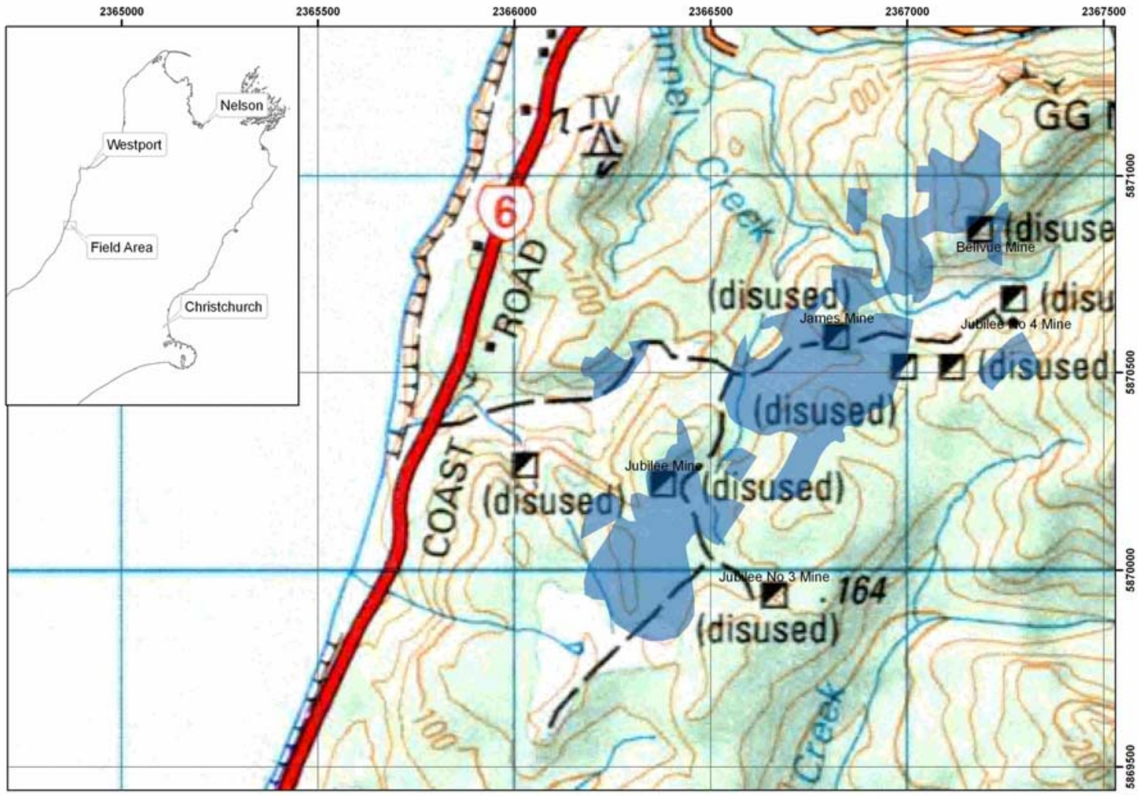

Figure 8: Mixing proposed AMD with current AMD - Hypothetical downstream impact

Sketch hypothetical downstream impact on map.

Table 3: Scenario 2 - Mix predicted AMD with clean Cannel Ck – high buffering capacity

	pH	flow	Al	Fe	HCO_3^-
Belluve AMD	2.6	0.5	70	50	0
Cannel Ck d/s	4.12	14	2.78	0.1	0
Cannel Ck u/s	7.8	12.6	0.3	0.5	200

4.3 Predicted ecological impacts

Goal

To assess the likely ecological impacts of development of a new mine at Bellvue, and determine if remediation treatments would be required.

Step 1

Baseline ecological assessment

Under most circumstances we would conduct a baseline survey to confirm background conditions. Ideally this would be a BACI study (i.e. Before – After – Control – Impact).

Number of sites: At this mine a BACI survey might typically include sampling at upstream sites, sites at the existing adits, at downstream sites in Cannel Creek and also nearby non-impacted streams (Figure 9). The upstream and non-impacted sites provide our "control" conditions. It is <u>absolutely</u> essential to have "control" (or "Reference") sites.

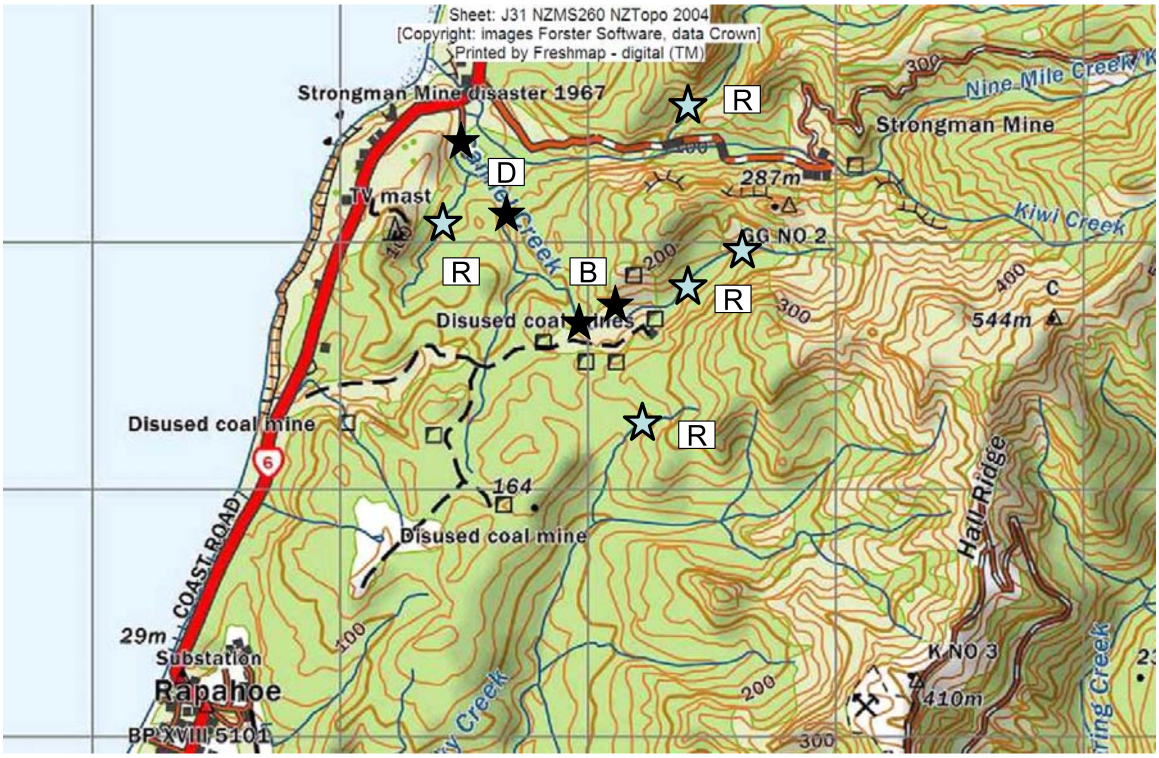

Figure 9. Possible sites for a BACI assessment at Bellvue (B = stream sites with existing Bellvue adit discharges, D = downstream Cannel Creek sites with existing AMD, R = possible Control sites, not impacted by existing AMD). We might have approx. 7 - 10 sites.

What parameters would be sampled:

a) Spot water chemistry – pH, conductivity, temperature, dissolved oxygen, dissolved metals (e.g. Fe, Al, Mn, Ni), possibly turbidity,
b) Benthic invertebrates – at a minimum qualitative samples (preferably quantitative)
c) ?Algae – at a minimum algal cover, hopefully quantitative
d) ?Fish – probably electric fishing, possibly night spotlighting

Step 2

Desktop exercise

In this case study we already have predicted water chemistry from rock geochemistry data, and we can draw on algae, invertebrate and fish data from our previous studies to give us an estimate of likely impacts.

Scenario 1 – the current situation
Bellvue @ adit – pH 2.6, dissolved Al & Fe 50 + 70 mg/l
Cannel Ck d/s – pH 3.2, dissolved Al & Fe 5.6 + 7.8 mg/l
Cannel Ck u/s – pH 7.8, dissolved Al & Fe 0.3 + 0.5 mg/l

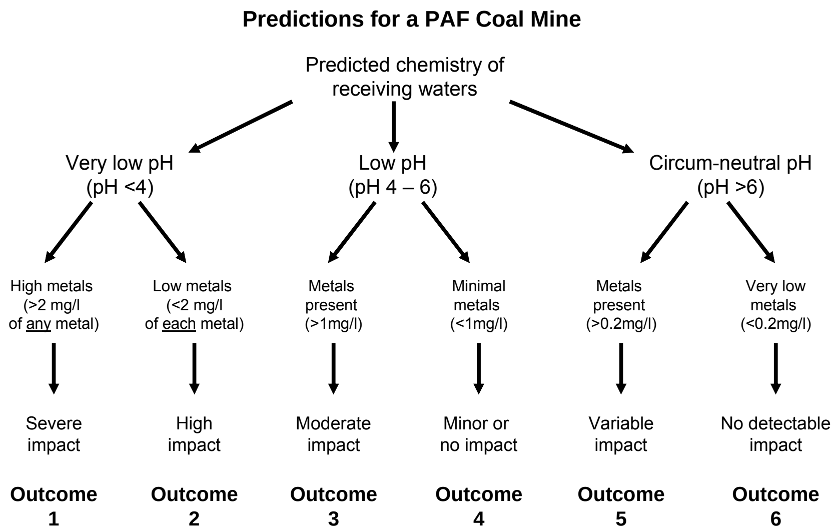

Figure 10: Ecological impact model

Ecological impact - Outcome 1 (Figure 10)

The most severe impact on stream ecosystems occurs when water is highly acidic (pH < 4) and has high concentration of metals. No New Zealand fish can survive for long in such water. Few macroinvertebrates of very limited diversity will be found in such streams. Algae and microbes, however, may be present, and even in high abundance in some cases. These communities tend to be dominated by a few taxa that are able to tolerate the stressful conditions.

Hypothetical algal, invertebrate and fish communities

Algae (%)	Bellvue	Cannel Ck	Control
Phormidium			1
Batrachospermum			20
Euglena	45		
Coenocystis			1
Characium			
Draparnaldia			30
Gloeocystis			31
Klebsormidium	53	1	
Microspora	2	80	
Microthamnion		10	
Mougeotia	2		
Mougeotia laevis		10	
Achnanthes			3
Diatoma			6
Eunotia sp A.			
Encyonema			
Fragilariforma			1
Gomphonema			6
Tabellaria			1
TOTAL TAXA	**4**	**4**	**13**

Invertebrates (m^2)	Bellvue	Cannel Ck	Control
Mayflies			
Deleatidium			44
Zephlebia			3
Stoneflies			
Austroperla			2
Megaleptoperla			1
Zelandobius			4
Spaniocerca	1	2	
Caddisflies			
Aoteapsyche			1
Neurochorema			
Oxyethira albiceps			2
Psilochorema		1	
Rakiura			1
Tiphobiosis			1
Zealandoptila			1
Dobsonflies			
Archichauliodes			5
True flies			
Aphrophila			2
Diamesinae		1	1
Empididae			1
Orthocladiinae	8	3	2
Beetles			
Scirtidae	7		
Worms			2
Spring-tails		1	
TOTAL TAXA	**3**	**5**	**16**

Fish (m^2)	Bellvue	Cannel Ck	Control
Crayfish			2
Long-fin eel			1
Inanga			12
Banded kokopu			5
Koaro			2
TOTAL TAXA	**0**	**0**	**5**

4.4 Management and remediation options

Factors influencing mine drainage

• Landform	**Steep, little flat land**
• Climate	**High rainfall**
• Mine type	**Open Cast**
• History	**Underground + AMD**
• Composition of strata	**PAF material present**
• Arrangement of strata	**PAF sandstone just above coal seam**
• Waste proportions	**Mostly NAF**
• Flow paths	**Mine above watertable**
• Flow rates	**0.7 L/sec**

↓

Mine planning & management options (Figure 11)

Pre-mining analysis

- **15% of samples contain pyrite or Fe stain, and PAF rock is close to top (5 m) of the coal seam**
- **No carbonate in cores**
- **Alkalinity of local water 10 ppm (low)**
- **High dissolved O_2**

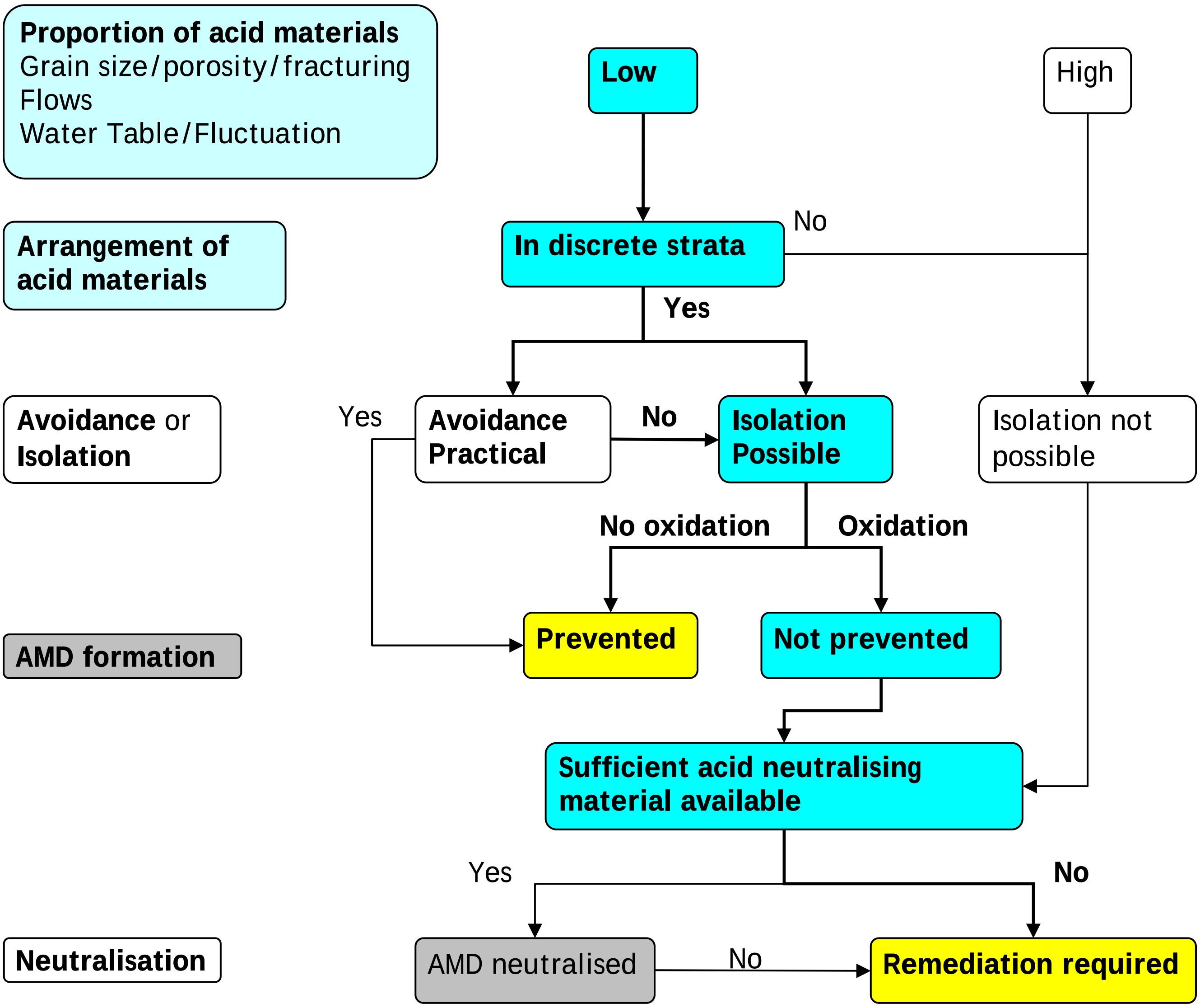

Figure 11: Selection of management techniques

Management options

Existing AMD

- Install drains above mine area to divert any clean water sources
- Capture adit water and treat AMD
- Install drain at base of cascade to capture, divert and treat any remaining AMD
- Remove any PAF waste rock on cascade and surrounds; blend or isolate depending on volume and cost of importing alkaline materials.

New mine

- Planning - location of waste rock piles
- Isolation
    - o Water diversion (as above); lowering of watertable unlikely option
    - o Identification and special handling of PAF materials (< 20% volume)
    - o PAF within 5 m of coal
    - o Removal of PAF material and capping to prevent oxidation

Exercise for Treatment of AMD at Bellvue Mine

Goal
Design appropriate AMD treatment system(s) at Bellvue Mine using the following assumptions and flow charts from the Framework document (Figures 12-14).

Assumptions

1. New mine will be open cut right over the current Bellvue Mine.
2. Historic AMD flow and chemistry may or may not change as mining proceeds (see Table 4).
3. Waste rock management may not be entirely successful and new AMD will be produced from an overburden dump east (upstream) of the existing AMD (see Table 4).
4. Historic AMD and the new AMD produce unacceptable impacts to Cannel Creek. Remediation is necessary to lower the concentrations of dissolved Al to below 1 mg/L and to raise the pH to near background levels.

Table 4: Parameters for Cannel Creek, historic AMD, and predicted new AMD from new mining.

	Cannel Creek Background	**Historic AMD at portal**	**Historic AMD at bottom of cascade**	**New AMD**
pH	7.28	2.71	2.65	2.65
DO (mg/L)	10.2	0.55	9.73	
Conductivity (µS/cm)	72.1	2280	2200	
Flow (L/s)	3.9	1.4	1.4	0.7
Acidity	0	680	550	635
Dissolved Al (mg/L)	0.3	52	40	70
Dissolved Fe (mg/L)	0.58	74	60	50
Dissolved Mn (mg/L)	<0.05		0.39	
Dissolved Ni (mg/L)	<0.03		0.17	
Acid Load (kg/d)		82	67	27

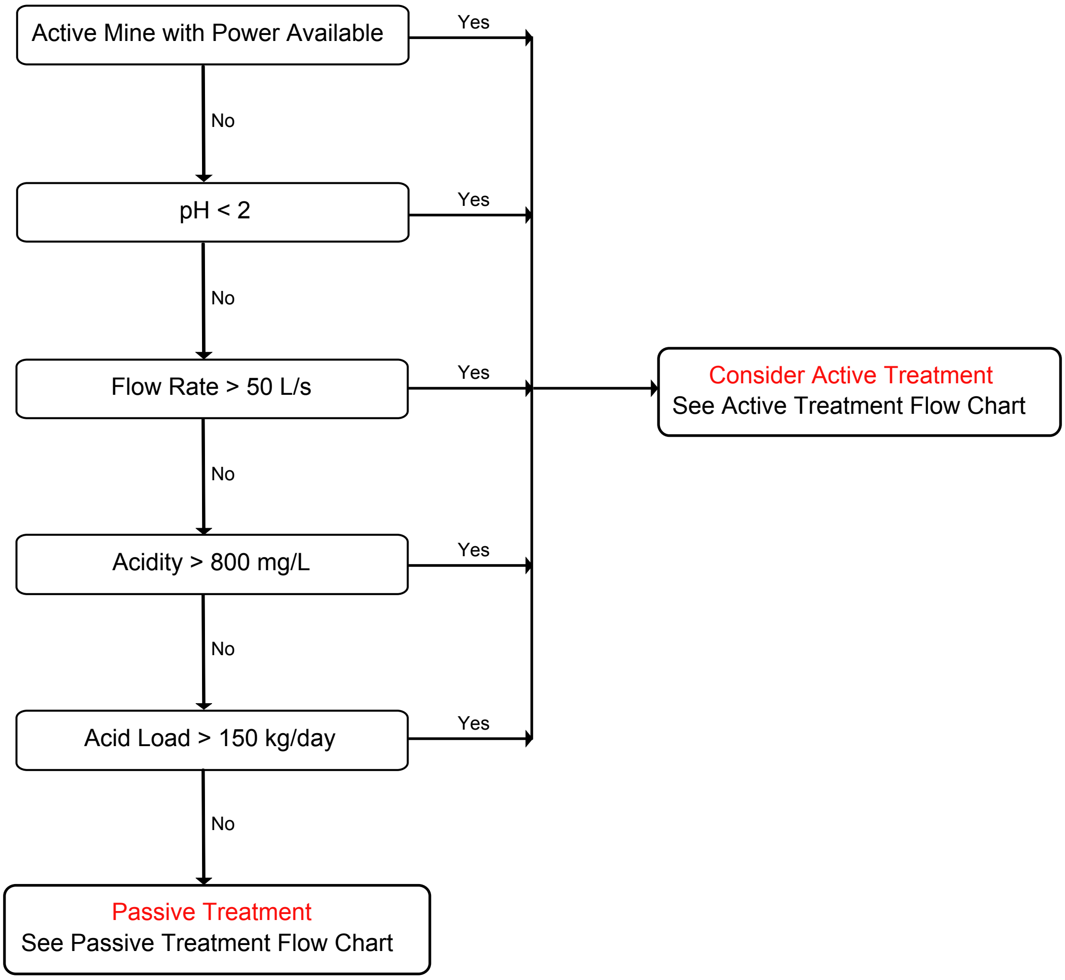

Figure 12: Flow chart to choose between active and passive treatment for AMD (modified from Waters et al., 2003).

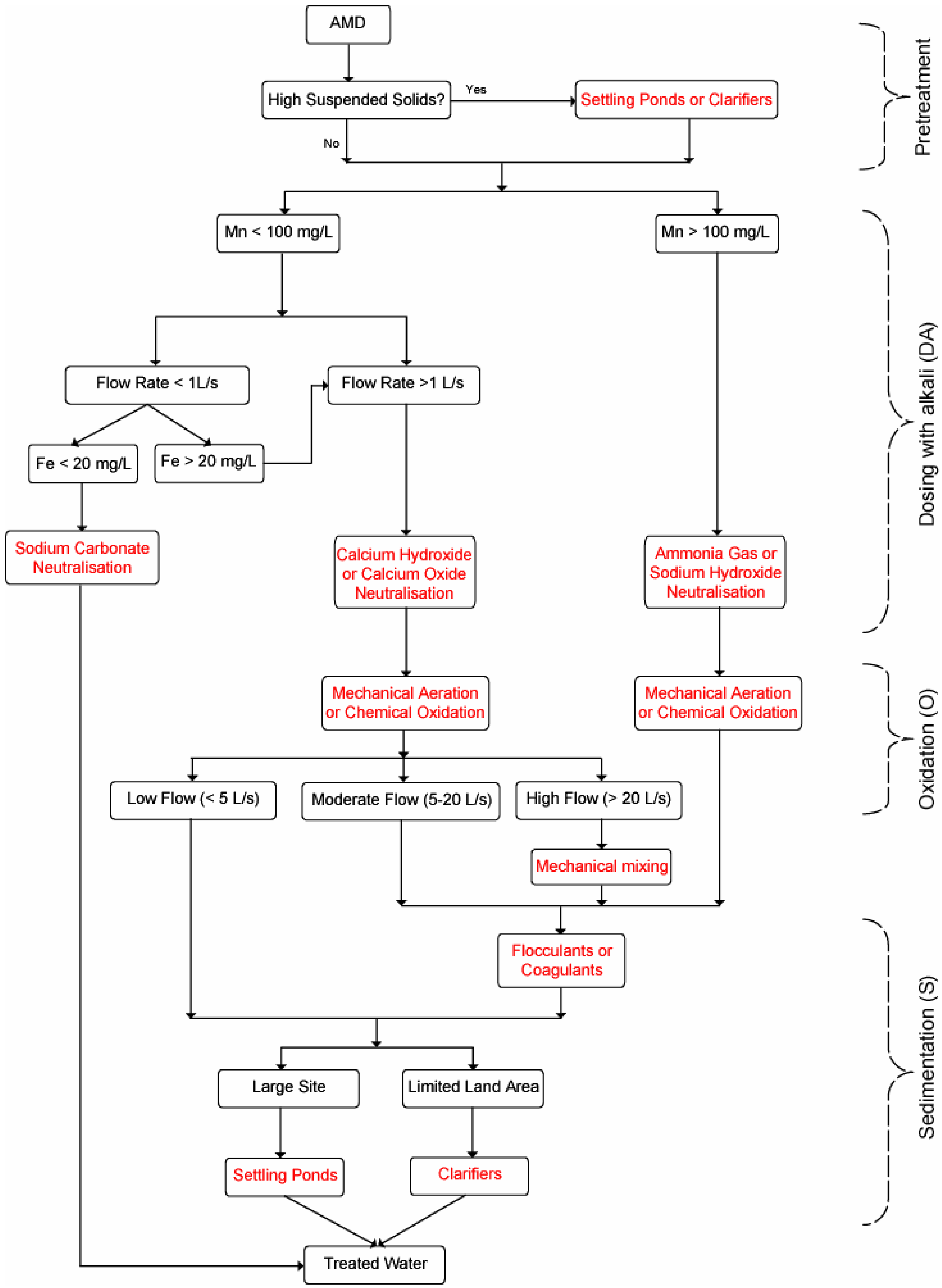

Figure 13: Flow chart to design a site-specific active treatment system for AMD (modified from Rajaram et al., 2001).

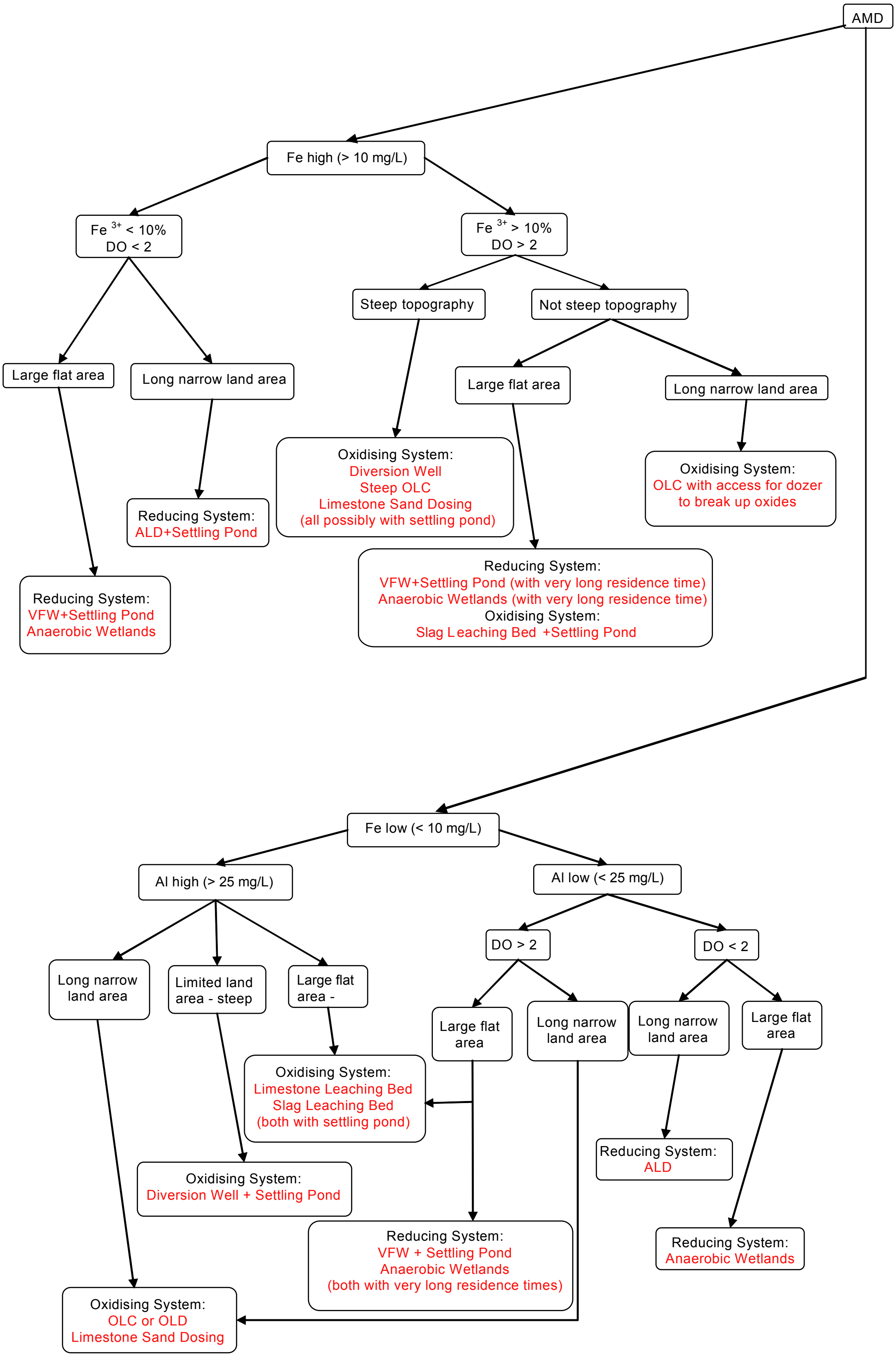

Figure 14: Flow chart to select among AMD passive treatment systems based on water chemistry, topography, and available land area (Trumm, 2007).

5 Friday Morning - Science Presentations

6 Acknowledgements

Funding for this research is provided by the Foundation for Research Science and Technology (FRST). Data has been supplied by Regional Councils and mining companies. Special thanks to Solid Energy New Zealand, Oceana Gold, Francis Group, West Coast Regional Council, the Department of Conservation, Environment Southland and Minerals West Coast.

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