Investigation of Remediation of Acid-Mine-Impacted Waters at Cannel Creek

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Summary

Project and Client

This report fulfils a training request from the West Coast Regional Council under an Envirolink Grant (WCRC3) and outlines a case study to demonstrate the steps required to select appropriate remediation options for acid mine discharges (AMD) from abandoned mines on the West Coast. Specifically, it outlines the approach to collection of the data required, and interpretation of those data to determine potential remediation options. The case study was undertaken at Cannel Creek, north-east of Greymouth.

Objectives

- Demonstrate sampling techniques and explain background to sampling strategies for determining remediation options for AMD, to West Coast Regional Council staff members during a field trip to and longitudinal study of Cannel Creek.
- Collate in a report the results of the sampling undertaken and outline the data interpretation required to select remediation options.

Methods and Results

A preliminary field trip, and a longitudinal study of water quality along Cannel Cr were undertaken. The field trip introduced the theory behind acid mine drainage and selection of remediation options, and included initial collection of water samples for laboratory analyses. The longitudinal study enabled assessment of the relative impact of different inputs to Cannel Ck. The results were:

- A marked decrease in pH in Cannel Creek from 5.79 to 3.55 and elevation in the concentrations of the dominant contaminants in the AMD, iron and aluminium, downstream of Bellvue Mine during preliminary sampling.
- Bellvue Mine AMD is the primary source of AMD to Cannel Creek contributing approximately 62% of the total hydrogen ion impact to Cannel Creek
- A second adit downstream of the Bellvue Mine and on the true right bank of Cannel Creek contributes approximately 33% of the total hydrogen ion impact.
- Remediation of the Bellvue AMD would likely result in a significant restoration of the water quality in Cannel Creek.
- The Bellvue Mine AMD emanates from an anoxic pool in the adit and flows down a steep, 40-m-long cascade and oxidising or reducing systems may be appropriate for remediation. Oxidising systems such as open limestone channels or diversion wells are likely to be most appropriate if systems are constructed on or below the cascade. Reducing systems such as an anoxic limestone drain or a vertical flow well may be most appropriate if systems are constructed near the pool in the adit.

Recommendations

- Additional data that captures the variation in water chemistry and flow rates of the Bellvue AMD, is required prior to selecting potential remediation options. Once potential solutions have been identified, it is recommended that small-scale trials be constructed to test the effectiveness of each potential solution.

1. Introduction

This report fulfils a training request from the West Coast Regional Council under an Envirolink Grant (WCRC3) and outlines a case study to demonstrate the steps required to select appropriate remediation options for acid mine discharges (AMD) from abandoned mines on the West Coast. Specifically, it outlines the approach to collection of the data required, and interpretation of those data to determine potential remediation options. The case study was undertaken at Cannel Creek, north-east of Greymouth.

2. Background

2.1 Site description

Cannel Creek has its head near Strongman Mine and joins with Griffin Creek to discharge into the Tasman Sea north of Rapahoe (Fig. 1). It receives discharge from several disused mine adits. Poor water quality, namely lowered pH and high conductivity, occurs downstream of these adits, and indicates an impact arising from acid mine drainage (AMD). The majority of the AMD discharging into Cannel Creek appears to arise from the adit of Bellvue Mine (Fig. 2), as pH in Cannel Creek drops from c. 7 upstream to c. 3 downstream of the mine adit. Previous water quality sampling shows that the AMD has a low pH (2.6) and high conductivity (1500 µs/cm). Flow from the adit is approximately 1 L/s.

Fig. 1 Location of Cannel Creek and Bellvue Mine, West Coast, South Island

Fig. 2 Acid mine drainage at Bellvue Mine on the West Coast of New Zealand

3. Objectives

- Demonstrate sampling techniques for and background to sampling strategies for determining remediation options for AMD, to West Coast Regional Council staff members Jonny Horrox and Steffi Henkel during the following activities:
    - Field trip and preliminary sampling (12 January 2006)
    - Longitudinal study to confirm primary source of AMD for Cannel Creek (1 March 2006).
- Collate in a report the results of the sampling undertaken and outline how the data is used to select remediation options.

4. Methods and Results

4.1 Field trip and preliminary sampling

The field trip aimed to provide the theory behind acid mine drainage and give a practical demonstration of sampling techniques and strategies required to assess potential remediation options. Specifically, the aspects covered were:

- The general cause of AMD, the extent of the AMD problem on the West Coast, and the effects of AMD on the ecosystem.

- The general sampling plan for AMD sites including the rationale for the analytes for which the samples are typically tested.
- The potential causes for differences in flow rates and chemistry for two abandoned underground mines (Bellvue and Jubilee) that discharge AMD to Cannel Creek.
- Active and passive remediation technologies used at AMD sites and how selection among these systems is based on site parameters, remediation goals, water chemistry, and flow rates.
- Practical demonstration of techniques including:
    - Measurement of flow rates of the AMD from the Bellvue Mine and of Cannel Creek
    - Measurement of field water-quality at both mine sites and the receiving stream, including pH, conductivity, dissolved oxygen, and temperature.
    - Collection of water samples for analysis (hot acidity, alkalinity, sulphate, aluminium, iron, manganese, nickel, and arsenic (both dissolved and total concentrations)) from the Bellvue AMD and from Cannel Creek upstream and downstream of the confluence with the Bellvue AMD.
    - Conduction of a titration experiment on the Bellvue AMD

The results of field measurements and laboratory analyses are presented in Table 1.

Table 1 Field measurements and analytical results for site visit, 12 January 2006

	Cannel Creek Upstream of Bellvue Mine AMD	**Cannel Creek Downstream of Bellvue Mine AMD**	**Bellvue Mine AMD**
pH	5.79	3.55	3.01
Conductivity	48	81	1837
DO (g/m^3)	9.94	9.75	8.39
Flow rates (L/s)	85	not measured	1.06
Hot Acidity (g/m^3)	12	22	550
Alkalinity (g/m^3)	3	<3	<3
Sulphate (g/m^3)	<10	20	750
Aluminium – dissolved (g/m^3)	0.1	0.8	40
Iron – dissolved (g/m^3)	0.34	0.37	60
Manganese – dissolved (g/m^3)	<0.05	<0.05	0.39
Nickel – dissolved (g/m^3)	<0.03	<0.03	0.17
Arsenic – dissolved (g/m^3)	<0.001	<0.001	<0.001
Aluminium – total (g/m^3)	0.2	1.5	40
Iron – total (g/m^3)	0.68	1.66	74
Manganese – total (g/m^3)	<0.05	<0.05	0.4
Nickel – total (g/m^3)	<0.03	<0.03	0.17
Arsenic – total (g/m^3)	<0.001	<0.001	<0.001

The most marked impact was the decrease in pH in Cannel Creek from 5.79 to 3.55 after the confluence with the Bellvue Mine AMD. In addition, the concentrations of the dominant contaminants in the AMD, iron and aluminium, were elevated downstream of Bellvue Mine.

This elevation is further highlighted if the flux (grams per second) of these contaminants is considered. In this case, the total iron present in the stream increased, from 0.06 g/s upstream of the AMD to 0.14 g/s downstream. Total aluminium increased from 0.02 to 0.13 g/s.

Titration experiment

Sequential titration of AMD with a base solution has recently been found by the AMD research community in the USA to be useful for determining remediation requirements to treat AMD to specified levels. Specifically, it assists in determining the amount of neutralising material needed to treat the AMD to a specified pH level or a specified concentration of iron or aluminium. Briefly, the titration is conducted by adding 0.5 ml of 2% NaOH to 250 ml of AMD and analysing the solution for pH and dissolved iron and aluminium. This process is repeated until the resulting pH of the AMD is 9.

The results for the Bellvue Mine water sample show that the majority of iron precipitates from solution at a pH of approximately 4 and that aluminium precipitates steadily from pH 4 to 5.5 (Fig. 3). Once the goals for water quality treatment are determined for a site such as the Bellvue AMD, these titration data can be used to design an appropriately sized treatment system.

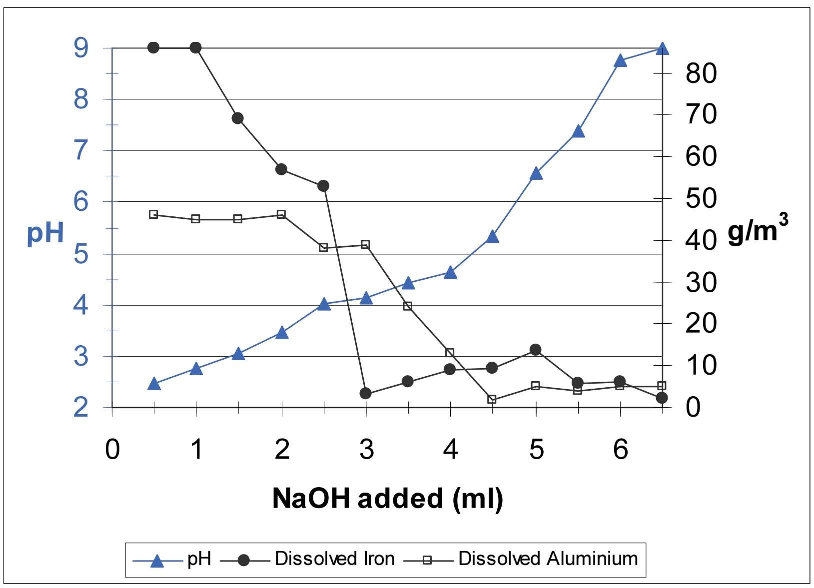

Fig. 3 Changes in pH and dissolved metal concentration during titration of Bellvue AMD with 2% NaOH.

4.2 Longitudinal study

During the initial field trip in January, the potential for other AMD sources affecting Cannel Creek was discussed. A number of abandoned underground mines downstream of Bellvue Mine may also discharge AMD into Cannel Creek (Fig. 1). If each of these mines discharges water of quality and quantity similar to the Bellvue Mine AMD, then remediation of the Bellvue AMD may result in minimal improvement to the quality of the water in Cannel Creek. As such, a longitudinal study to determine the significance of other AMD sources was undertaken.

This study was conducted on 1 March 2006 and involved walking the length of Cannel Creek from the Magazine Road Bridge (the WCRC sampling point for Cannel Creek) to the Bellvue Mine, making observations of the physical condition and measuring field parameters periodically in Cannel Creek and every input to Cannel Creek (Table 2, Appendix 1). Inputs to Cannel Creek were two tributaries (Sites 2 and 5) and six seepages including four from mine adits (Sites 7, 9, 12, 14, 19, and 20). Field observations included resuspendable solids, fine sediment deposits, imbeddedness, and water appearance. Field parameters measured were pH, conductivity, dissolved oxygen, temperature, and flow rate (with the exception of the first tributary). Selected samples from Cannel Creek were collected for laboratory analysis for sulphate, a diagnostic analyte for AMD, and additional samples were also analysed for acidity, iron (total and dissolved), and aluminium (total and dissolved).

The pH from each of the two tributaries was greater than 7, and for one of the seepages from the ground the pH was greater than 6. The remaining five seepages exhibited low pH characteristic of AMD. Starting from the Magazine Road Bridge and extending upstream along Cannel Creek, these seepages were:

- Drainage with pH of 2.41 from an adit on the true right bank (Site 7)
- Drainage with a pH of 3.25 from an adit on the true left bank (Site 9)
- Seepage with a pH of 3.75 from the ground on the true left bank (Site 14)
- The Bellvue Mine AMD with a pH of 2.65 (Site 19)
- The Jubilee Mine AMD with a pH of 2.74 (Site 20).

The sulphate results for the Jubilee Mine AMD, Bellvue Mine AMD, and the adit drainage at Site 7 also confirm that these three drainages are AMD (no sulphate analyses were conducted for the adit drainage at Site 9 or the seepage at Site 14). Background sulphate concentration in Cannel Creek (upstream of the Bellvue AMD) was less than 10 g/m^3. Sulphate in the Jubilee and Bellvue mines' AMD was 550 g/m^3 and 900 g/m^3, respectively. Downstream of the confluence with these AMDs, the sulphate concentration in Cannel Creek was elevated to 205 g/m^3. The adit drainage at Site 7 contained a very high sulphate concentration (33 800 g/m^3), which further elevated the sulphate in Cannel Creek to 360 g/m^3. Downstream of Site 7, the sulphate concentration in Cannel Creek dropped from 360 to 290 g/m^3 at Site 1 (Magazine Road Bridge). This suggests that there are no other suspected AMD impacts on Cannel Creek downstream of Site 7 and shows the usefulness of sulphate in identifying suspected AMD impact on streams.

Iron and aluminium concentrations in the drainage at Site 7 and in the Bellvue Mine AMD also indicate that these are significant AMD input sources to Cannel Creek (no metal analyses were conducted on the other three suspected AMDs).

Table 2 Field measurements and analytical results for longitudinal study conducted on 1 March 2006.

Site	Temp (°C)	Cond (uS/cm)	DO (mg/L)	pH	Flow (L/s)	Hot Acidity (g/m^3)	Al dissolved (g/m^3)	Al total (g/m^3)	Fe dissolved (g/m^3)	Fe total (g/m^3)	SO_4 (g/m^3)	Comment
Site 1. Cannel Ck @ 50 m u/s of Magazine Rd Bridge	12.8	675		3.3	13.5	106	12.2	13.6	0.99	7.2	290	
Site 2. First tributary on true left of Cannel Ck	12.8	234		7.89								
Site 3. Cannel Ck @ Site 3	12.7	735		3.32							290	
Site 4. Cannel Ck @ Site 4	13	760		3.25								
Site 5. Second tributary on true left of Cannel Ck	12.3	228		7.14	0.6						16	This creek contains abundant mayflies and potamopyrgus snails – there is historical mining activity in this catchment
Site 6. Cannel Ck @ 5 m u/s of Site 5 second tributary inflow	13.2	917		3.11							360	
Site 7. Adit drainage, true right	14.9	4760		2.41	0.25	1300	216	216	134	144	33800	
Site 8. Cannel Ck @ 30 m u/s of Site 7 adit inflow	13.2	638		3.19								
Site 9. Adit drainage, true left @ 80 m u/s Site 7	13	1571		3.25	0.05							
Site 10. Cannel Ck @ 5 m u/s of Site 9 adit inflow	13.1	651		3.11							180	Appeared to be significant lack of iron precipitate on substrate
Site 11. Cannel Ck @ Site 11	13	658		3.07								
Site 12. Seepage A true left	13.7	216		6.12	0.1							Fluffy looking iron precipitate
Site 13. Cannel Ck @ 5 m u/s Site 12	13.3	690		3.16								Dirty dark brown/grey algae on substrate
Site 14. Seepage B true left	15.5	226		3.75	0.025							
Site 15. Cannel Ck @ 5 m u/s Site 14	14.1	715		3.05								
Site 16. Cannel Ck @ clearing	13.6	736		3.03								
Site 16b. Cannel Ck @ d/s Jubilee (5m d/s of culvert)	13.4	679	9.44	3.2								Sample taken; lower flow than @ culvert; nearly entire bed covered in fine FeOx-sediment (orange-brown colour)
Site 17. Cannel Ck @ d/s Rd culvert	13.5	728		3.06								
Site 17a. Cannel Ck @ d/s Jubilee (@ exit of culvert)	13.4	671	9.54	3.18		132	11.2	12.5		30	205	
Site 17b. Cannel Ck @ 9 m d/s Bellvue (1 m u/s Jubilee)	13.4	509	9.46	3.29								
Site 17c. Cannel Ck @ 4 m d/s Bellvue	13.3	326	9.65	3.3								
Site 18. Cannel Ck @ 5 m u/s Bellvue	12.9	72.1	10.2	7.28	3.9	6	0.3	0.3	0.58	1.34	<10	Streambed: wood, gravel (light orange/grey-brown); light anoxic smell when disturbing

Site	Temp (°C)	Cond (uS/cm)	DO (mg/L)	pH	Flow (L/s)	Hot Acidity (g/m^3)	Al dissolved (g/m^3)	Al total (g/m^3)	Fe dissolved (g/m^3)	Fe total (g/m^3)	SO_4 (g/m^3)	Comment the sediment
Site 19. Bellevue @ Pool (Mine entrance)	13.8	2280	0.55	2.71		680	52	65	74	105	900	Sample taken; lots of fine sediment on the bottom of the pool, but no FeOx-colour
Site 19b. Bellevue AMD @ 10 m u/s confluence	14.7	2200	9.73	2.65	1.4							Filamentous algae only in small pools, but not on stony bed
Site 20. Jubilee AMD 40 m d/s Mine	12.3	1540	10.5	2.74	0.5						550	Sample taken; FeOx visible on stream bed (orange colour); ~ 50% of bed covered in filamentous green algae (100% in pools)

The significance of the different AMD sources to the water quality of Cannel Creek can be determined by establishing the relative contribution of hydrogen ions from each of the inputs (Table 3). This in turn can be determined from the pH and metal concentration data collected. Briefly, hydrogen ions are derived from two sources: hydrogen ions present in the solution in aqueous form at concentrations greater than background water (for Cannel Creek, background pH was 7.28), and hydrolysis and precipitation of iron and aluminium. Aqueous hydrogen ions are measured as units of pH, which is the negative logarithm of the hydrogen ion concentration. Hydrolysis of one mole of dissolved ferric iron (Fe^{3+}) and precipitation of ferric hydroxide ($Fe(OH)_3$) produces three moles of hydrogen ions. Likewise, hydrolysis of one mole of aqueous aluminium (Al^{3+}) and precipitation of aluminium hydroxide ($Al(OH)_3$) produces three moles of hydrogen ions. Combining pH, concentrations of iron and aluminium (dissolved), and flow rate allows the calculation of the total load of hydrogen ions from each source. In summary, to determine the relative contribution of hydrogen ions to Cannel Creek, the following methodology was used:

1. Eight input sources to Cannel Creek were identified (five of these classified as AMD as mentioned above).
2. The total hydrogen ion loading rate in moles per minute for each source was calculated, assuming any pH below 7.28 contributed hydrogen ions and any iron and aluminium hydrolysis contibuted hydrogen ions. Unfortunately, iron and aluminium concentrations were not determined for two of the AMD sources, Site 9 and Site 14; however, the relative loading of hydrogen ions from these sources would not be great considering their very low flow rates.
3. All sources were added together to determine the total loading of hydrogen ions in moles per minute to Cannel Creek from all eight sources.
4. The percentage contribution to the total from each source was determined.

Using this approach, downstream of all the input sources to Cannel Creek, the Bellvue AMD is determined to provide approximately 62% of the hydrogen ions and the adjacent Jubilee Mine AMD is responsible for approximately 5%. After the Bellvue AMD, the next largest contributor of hydrogen ions is an AMD from an adit on the true right bank of Cannel Creek (Site 7). This site contributes approximately 33% of the total impact to Cannel Creek. The remaining sources of impact amount to less than 1% of the total impact to Cannel Creek.

The results of the longitudinal study confirm that the Bellvue Mine adit is the primary contributor of AMD to Cannel Creek. As such, remediation of the Bellvue AMD would likely result in a significant restoration of the water quality in Cannel Creek.

Table 3 Relative contributions of hydrogen ions to Cannel Creek from all sources identified through the longitudinal study.

Location	Flow rate (L/s)	pH	Dissolved Fe (mg/L)	Dissolved Al (mg/L)	Acidity loading (tons/year)	Hydrogen ions (moles per minute from metal precip+pH)	Hydrogen ion contribution to total
Site 18 - Background Cannel Creek (upstream of all inputs)	3.9	7.28	0.58	0.3	0.7	0.9	
Sites 19 and 19B Bellvue AMD	1.4	2.65	74	52	30.0	60.5	62%
Site 20 Jubliee AMD	0.5	2.74	6.71	3.23		4.6	5%
Site 14 Seepage B True Left	0.025	3.75				0.02	0.02%
Site 12 Seepage A True Left	0.1	6.12				0.0003	0.0003%
Site 9 Adit Drainage True Left	0.05	3.25				0.1	0.10%
Site 7 Adit Drainage True Right	0.25	2.41	134	216	10.2	31.6	33%
Site 5 Second Tributary True Left	0.6	7.14				0.00004	0.00004%
Site 2 First Tributary True Left	minimal	7.89					
Site 1 End of Cannel Creek (Magazine Rd)	13.5	3.3	0.99	12.2	45.1	92.9	

4.3 Selection of remediation systems

To select appropriate remediation systems, information on the space available for remediation systems is required in addition to water quality and flow data. The topography at Bellvue Mine in the vicinity of the AMD is both steep (a cascade of about 40 m) and relatively flat (a dirt road with very slight gradient at the bottom of the cascade). The flat area could be used to install remediation systems. In addition, a pool containing water with a low dissolved oxygen content (< 1 mg/L) was present just above the cascade and provides additional possibilities for remediation.

Using these data, together with the water quality and flow data discussed above, preliminary remediation options can be selected using the flowchart specified in Fig. 4 (from Trumm 2006). As the iron concentration is relatively high, remediation options from the first half of the flowchart are the most appropriate. As the dissolved oxygen (DO) concentration of the AMD is greater than 2, the percent of iron in the ferric state (Fe^{3+}) is likely to be much greater than 10% suggesting oxidising remediation systems are most appropriate. The topography in the vicinity of the AMD is both steep and relatively flat. With these parameters, the flowchart suggests the following options: (1) an open limestone channel (OLC) down the cascade, (2) a diversion well (DW) at the base of the cascade, (3) a limestone sand dosing system at the top of the cascade, or (4) an OLC at the base of the cascade.

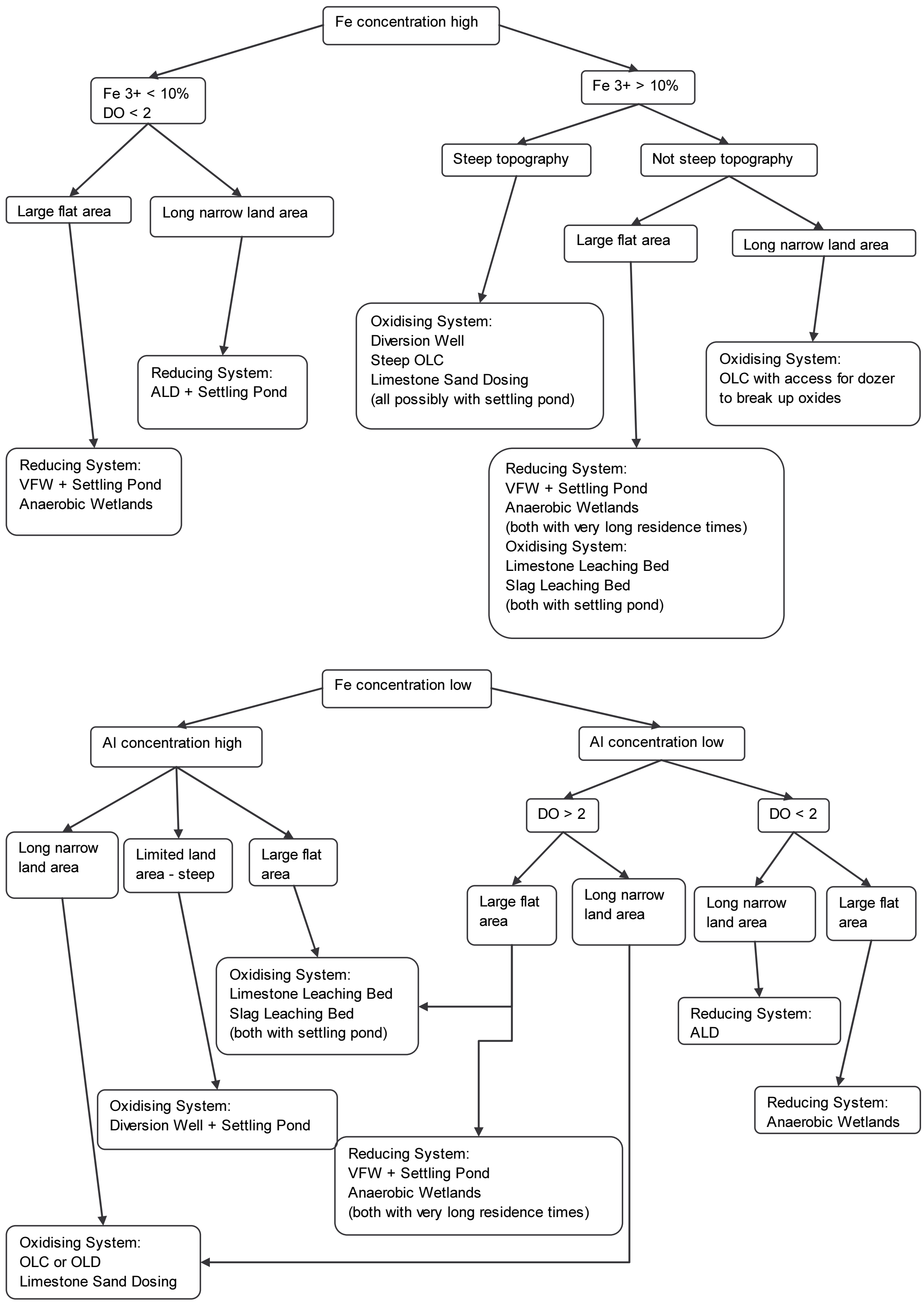

Fig. 4 Flowchart to use to select among AMD passive treatment systems (Trumm 2006).

An alternative approach is to treat the water in the anoxic pool at the top of the cascade. It is likely that the majority of the iron in this pool is in the reduced ferrous (Fe^{2+}) form, due to the low dissolved oxygen content of the pool. If so, reducing systems such as an anoxic limestone drain (ALD), a vertical flow wetland (VFW), or an anaerobic wetland may also be appropriate remediation options.

However, to determine more specifically appropriate systems to treat the Bellvue AMD, more data are required. We recommend that monthly water quality samples, capturing both high- and low-flow events, be collected for one year to more accurately estimate the variability in water quality. The concentration of ferrous iron (Fe^{2+}) relative to ferric iron (Fe^{3+}) should also be determined. It is also recommended that a datalogger be installed to determine the range in flow rates and the effect of precipitation events on flow rates. Finally, it is recommended that small-scale trials of potential solutions be constructed on site to determine the cost-effectiveness of each solution prior to constructing a full-scale remediation system.

4.4 Overview

This report has provided a case study to illustrate data collection and interpretation to select appropriate remediation options for AMD from specific sources such as the Bellvue Mine. These steps form steps 1 and 2 in the process of selecting remediation options outlined below:

1. Data collection – water quality and flow data
    - Determine AMD water chemistry by sampling monthly for approximately one year
        - Field measurements: pH, conductivity, temperature, dissolved oxygen, Fe^{2+} concentration, titration analysis (at least once)
        - Laboratory analyses: Fe, Al, Mn, Ni, As (dissolved and total concentrations), sulphate, hot acidity, titrations prepared in the field and laboratory-analysed for metals (dissolved and total)
    - Determine range of flow rates and response of flow to precipitation events, either by spot sampling or preferably via data logger. Also determine effect of flow variation on water chemistry by sampling during these events
    - Document surface topography and available land area for treatment systems
2. Selection of potential remediation options (there may be more than one) using collected data and flow chart
3. Determination of treatment goals (water quality endpoints) and requirements for remediation options. This includes using the titration results from step 1 to establish the appropriate treatment level (including amount of neutralising material required).
4. Determination of the mass of contaminants to be removed from AMD. These data are necessary to design appropriately sized settling ponds, and to establish pilot trials.
5. Pilot trials to determine most-cost-effective remediation options.

5. Summary

This work has provided a case study to outline the approach to data collection for a typical AMD site, and provides an illustration of how that data are used to select potential remediation options. The case study was undertaken at Cannel Creek, north-east of Greymouth.

Sampling of the AMD input sources to Cannel Creek indicates that the Bellvue Mine AMD contributes approximately 62% of the total hydrogen ion impact to Cannel Creek. A second adit downstream of the Bellvue Mine and on the true right bank of Cannel Creek contributes approximately 33% of the total hydrogen ion impact. Thus, remediation of the Bellvue Mine AMD would likely help to restore the water quality in Cannel Creek.

Based on the preliminary water quality sampling undertaken, oxidising or reducing remediation systems may be appropriate. The AMD emanates from an anoxic pool in the adit and flows down a steep, 40-m-long cascade. If systems are constructed on or below the cascade, oxidising systems such as open limestone channels or diversion wells are likely to be most appropriate, but if systems are constructed near the pool in the adit, reducing systems such as an anoxic limestone drain or a vertical flow well may be most appropriate.

6. Recommendations

- Additional data should be collected from the Bellvue AMD, including water chemistry and flow rates, prior to selecting potential remediation options. Specifically, we recommend that monthly water quality samples, capturing both high- and low-flow events, be collected for one year to more accurately estimate the variability in water quality; the concentration of ferrous iron (Fe2+) relative to ferric iron (Fe3+) should be determined; and a datalogger be installed to determine the range in flow rates and the effect of precipitation events on flow rates.
- Once potential solutions have been identified, it is recommended that small-scale trials be constructed to test the effectiveness of each potential solution.

7. Reference

Trumm D 2006. West Coast Coal and Gold Mine Drainage Workshop – field trip notes. West Coast Coal and Gold Mine Drainage Workshop, 4 May 2006, Westport, New Zealand. Joint Workshop CRL Energy, University of Canterbury, University of Otago, and Landcare Research.

Appendix 1 Additional field observations collected during longitudinal study

Site	Easting	Northing	Resuspend-able solids	Fine sediment deposits	Embedded-ness	Water appearance[1]	Weather[2]	Weather past 24 h
Site 1. Cannel Ck @ 50 m u/s of Magazine Rd Bridge	2366465	5871365						
Site 2. First tributary on true left of Cannel Ck	2366520	5871285						
Site 3. Cannel Ck @ Site 3	2366693	5871237						
Site 4. Cannel Ck @ Site 4	2366697	5871237						
Site 5. Second tributary on true left of Cannel Ck	2366760	5870855						
Site 6. Cannel Ck @ 5 m u/s of Site 5 second tributary inflow								
Site 7. Adit drainage, true right	2366859	5870917						
Site 8. Cannel Ck @ 30 m u/s of Site 7 adit inflow								
Site 9. Adit drainage, true left @ 80 m u/s Site 7								
Site 10. Cannel Ck @ 5 m u/s of Site 9 adit inflow								
Site 11. Cannel Ck @ Site 11								
Site 12. Seepage A true left	2366970	5870676						
Site 13. Cannel Ck @ 5 m u/s Site 12								
Site 14. Seepage B true left								
Site 15. Cannel Ck @ 5 m u/s Site 14								
Site 16. Cannel Ck @ clearing	2367156	5870694						
Site 16b. Cannel Ck @ d/s Jubilee (5m d/s of culvet)			8	9	2	4	3	fine/overcast
Site 17. Cannel Ck @ d/s Rd culvert								
Site 17a. Cannel Ck @ d/s Jubilee (@ exit of culvert)			6.5	7.5	rock/concrete	4	3	fine/overcast
Site 17b. Cannel Ck @ 9 m d/s Bellvue (1 m u/s Jubilee)						4	3	fine/overcast
Site 17c. Cannel Ck @ 4 m d/s Bellvue						4.5	3	fine/overcast
Site 18. Cannel Ck @ 5 m u/s Bellvue			4	4	1	1	3	fine/overcast
Site 19. Bellevue @ Pool (Mine entrance)						1	2.5	fine/overcast
Site 19b. Bellevue AMD @ 10 m u/s confluence			3	3	9	1	3	fine/overcast
Site 20. Jubilee AMD 40 m d/s Mine			2	2	9.5	1	2.5	fine/overcast

[1] - (Clear) 1 2 3 4 5 (Turbid)
[2] - 1 = Fine; 2 = Overcast; 3 = Drizzling; 4 = Raining