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Herbert Stream AMD Remediation - Preliminary Conceptual Design

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Introduction

The purpose of this report is to present a conceptual design for remediation of acid mine drainage (AMD) at Herbert Stream on the Stockton Plateau, West Coast. This design is based on the results of trial remediation experiments conducted at the site in 2005 and 2006.

Remedial Action Objectives

The remedial action objectives for the Herbert Stream AMD are to restore the water quality to a level at which macroinvertebrates native to the Stockton Plateau can survive in the stream. Pending further refinement of water quality parameters necessary for the survival of macroinvertebrates, Solid Energy New Zealand Limited (SE) has specified that dissolved aluminium concentrations should be reduced to below 1 mg/L.

Site Remediation Trials

Three trial remediation systems have been operating at the site for over 2 months. These systems consist of an open limestone channel (OLC), a reducing and alkalinity producing system (RAPS), also known as a vertical flow wetland, and a horizontal flow limestone leaching bed with a vertical flushing capability (LLB). The OLC and the LLB are constructed only out of limestone, whereas the RAPS contains spent mushroom compost as the first layer that the AMD passes through. Since 20 October 2005, a datalogger has been recording flow rates in the AMD on a 15-minute basis. Samples were collected from the AMD and the outlets from each system seven times and laboratory analysed for total and dissolved metals (aluminium, iron and manganese). The samples were also analysed for acidity, sulphate, and calcium. Field data collected during these sampling events included pH, temperature, conductivity, dissolved oxygen (DO), flow rates, and one occasion, ferrous iron concentration.

AMD Water Quality and Flow Rate

Samples collected from the AMD from 5 December 2005 to 9 February 2006 indicate the following range in water chemistry:

- pH: 2.98 to 3.27
- Acidity: 68 to 106 mg/L
- Dissolved Aluminium: 2.9 to 9.4 mg/L
- Dissolved Iron: 0.33 to 3.45 mg/L
- Dissolved Manganese: 0.39 to 0.92 mg/L

AMD flow rates from 20 October to 15 December 2005 averaged 5.3 L/s with a maximum of 26.6 and a minimum of 2.3 L/s. High flow rates occurred over very brief time periods. For example, the sequence of flow rates for the highest recorded flow is as follows: 04:00 = 6.5 L/s; 04:15 = 9.0 L/s; 04:30 = 9.3 L/s;

04:45 = 26.6 L/s; 05:00 = 10 L/s; 05:15 = 6.7 L/s; 05:30 = 5.9 L/s. For treatment systems such as an LLB or a RAPS, higher flow rates result in lower retention time of the AMD in the treatment media and less time available for AMD treatment. It is likely that during the high flow events at Herbert Stream, the concentration of dissolved metals is lower in the AMD due to dilution. If this is the case, reduced residence time within the treatment system during short, high flow events, should not substantially alter the quality of the treated water. Additional samples during high flow events are required to verify this interpretation.

Remediation Trial Results

Remediation trials began on 5 December 2005 and as of 6 March 2006 are ongoing. The data used in this analysis cover the period from 5 December 2005 to 9 February 2006 (a period of 66 days). Flow rates through the systems were controlled to regulate the time that the AMD water resided in the limestone layer for each system because residence time determines the level of treatment that can be accomplished. The residence time in the LLB and the RAPS ranged between 11 and 35 hours. The OLC residence time was initially only 2 minutes and later increase to 17 hours. The initial short residence time in the OLC was designed to examine how rapidly the limestone cobbles in the channel became coated with ferric hydroxide precipitates. The longer residence time later in the OLC was designed to test the treatment effectiveness of the system. Data from the trials and graphs of system performance are included in the Appendix.

Both the LLB and the RAPS units raised the pH of the AMD consistently to near neutral at all residence times. In the LLB, dissolved aluminium concentrations were lowered to between 0.4 mg/L to below detection limit (0.1 mg/L), dissolved iron concentrations were lowered to between 0.08 mg/L to below detection limit (0.05 mg/L), and dissolved manganese concentrations were lowered to between 0.58 and 0.04 mg/L. In the RAPS unit, dissolved aluminium concentrations were lowered to the detection limit (0.1 mg/L), dissolved iron concentrations were lowered to between 0.09 to 0.39 mg/L, and dissolved manganese concentrations were lowered to between 0.03 and 0.79 mg/L.

The concentration of DO in the RAPS unit was consistently below 1 mg/L, compared to the untreated AMD DO of 8 to 12 mg/L, indicating that reducing conditions were being achieved in the unit. In addition to DO, the percent of total iron in the ferrous state is an indication of the degree to which water is in a reducing state. On day 9 February 2006, 88% of the iron in the untreated AMD was in the oxidised ferric state and 100% of the iron in the RAPS effluent was in the reduced ferrous state.

For the OLC, once the residence time was raised to 17 hours, the pH in the AMD reached 5.6. Samples for laboratory analysis have not been collected since the residence time has been increased so treatment effectiveness of the OLC cannot be determined.

Preliminary Remedial Action Design

Conceptual Design

The results suggest that the RAPS and the LLB are each adequate systems to treat the AMD. The OLC may also be effective, however, the length of channel required to treat the AMD would likely exceed the available land area. It is recommended to use an LLB with vertical flushing capability for full-scale treatment for the following reasons:

- total iron concentrations in the AMD are low, therefore armouring of limestone in an oxidising system is not a significant concern;
- although aluminium concentrations are greater than iron in the AMD, aluminium does not armour limestone to same extent as iron;
- operation and maintenance is easier in the LLB compared to a RAPS;
- AMD sites with variable flow rates are easier to treat with oxidising systems than with reducing systems;
- cost is lower in a simpler system such as an LLB compared to a RAPS; and,
- sites in the USA with similar chemistry and flow rates have been successfully treated using an LLB.

The full scale system will consist of the following components:

- Collection chamber and piping to convey the AMD from the base of the overburden stockpile to the treatment site.
- An LLB with a vertical flushing capability constructed on the relatively flat area above the Herbert Stream on the true right bank.
- Two ponds immediately adjacent to the LLB to serve as flushing/settling ponds.
- A third settling pond prior to discharge back to the Herbert Stream.

It is also recommended that any sources of unimpacted water that flow into the Herbert Dam be pretreated with limestone riprap. This will serve to buffer the water with alkalinity which can reduce the level of acidity in the AMD downstream of the Herbert Dam.

An LLB with a vertical flushing component is a relatively new design developed in the USA to help maintain adequate residence time in treatment systems. Retention time is a key variable in AMD treatment. Long retention in treatment systems ensures adequate dissolution of treatment media. Long retention in settling ponds is vital to ensure adequate settling of particulate matter. Systems such as RAPS and LLB accumulate precipitates such as ferric and aluminium hydroxides that block passages between limestone cobbles and reduce residence time. These systems are typically designed with a flushing capability to remove precipitated compounds and restore residence time. However, if preferential pathways have formed through the treatment media, flushing only enhances the formation of these pathways rather than removing blockages in other parts of the system.

The LLB with vertical flushing is designed to prevent this problem. The system normally operates with a horizontal-flow-only component. The water level in the LLB is typically kept just below the top of the limestone surface to help induce horizontal flow. Flushing through the LLB operates only with a vertical flow component which tends to break up any preferential horizontal flow pathways and restore residence time.

The vertical/hybrid flow design was used in the LLB field remediation trial. During normal operation, flow was consistently in a horizontal direction and flushing involved vertical-only flow. To test the effectiveness of flushing removing accumulated precipitates, the system was flushed on 19 January 2006. The entire volume of AMD in the system was flushed over a 20 minute period into a holding tank, the AMD was mixed to adequately suspend the captured precipitates, and a laboratory sample was collected to determine the proportion of contaminants flushed (see data in Appendix). The results show that approximately 10% of the accumulated manganese was flushed, 16% of the accumulated aluminium was flushed, and 55% of the accumulated iron was flushed. More rapid flushing may be more effective in removing accumulated precipitates. The size of the limestone in the LLB trial was approximately 1 to 2 cm in diameter. A larger cobble size would enable higher permeability and a more rapid flushing rate. It is recommended that an average size of 9 cm diameter be used in the full-scale LLB.

Design Parameters

AMD Water Quality

The AMD water quality was assessed during the remediation trials. Water quality parameters used for design of the treatment system include:

- Flow Rate = 5.3 L/s average (25 L/s maximum)
- Acidity = 90 mg/l
- Iron = 3.7 mg/l
- Aluminium = 8.5 mg/l
- Manganese = 0.7 mg/l

Treatment System Operating Parameters

Treatment system operating parameters are based on recommendations in the literature and the results of the field trials. During the remediation trial the LLB was effective at residence times as low as 10 hours. The following parameters have been used in the design of the full-scale remediation system:

- Water residence time in the system of no less than 20 hours
- Minimum lifespan of 25 years
- Water residence time in flush pond/settling pond of no less than 20 hours

Treatment System Components

AMD Collection System

An inlet control structure should be installed at the base of the Herbert Dam to collect the AMD and transfer the entire AMD stream into a single PVC pipe sized to accommodate the maximum flow expected (25 L/s). The piping should convey the AMD to the treatment area located downstream on the true right back of Herbert Stream.

LLB Dimensions

The LLB should be directly excavated into the hard rock pavement area downstream of the Herbert Dam on the true right bank of Herbert Stream. Alternatively, a portion of the pond can be constructed above ground. The top of the pond must be below the elevation of the AMD collection system. The sides of the pond should have a 2:1 slope (2 run-of-slope to 1 rise-of-slope). The top dimensions should be 25 metres wide by 48 metres long and the bottom dimensions should be approximately 17 metres wide by 40 metres long. A geotextile liner should be used at the base and sides of the LLB to prevent escape of precipitates and AMD into the local environment.

Bedding Stone

Bedding stone at the base of the LLB should consist of 123 cubic metres of AASHTO #57-size calcareous sandstone with a calcium carbonate equivalent (CCE) of 48%. AASHTO #57 size is defined as:

- 100 % passes 37.5mm sieve
- 95-100% passes 25mm sieve
- 25-60% passes 12.5mm sieve
- 0-10% passes 4.75mm sieve
- 0-5% passes 2.36mm sieve

The top dimensions of the bedding stone should be approximately 18 metres wide by 41 metres long and it should be 0.17 metres thick.

Treatment Media

The treatment media, placed over the bedding stone, should consist of 1100 cubic metres of AASHTO #1-size limestone with a CCE of at least 90%. AASHTO #1 size is defined as:

- 100 % passes 100mm sieve
- 90-100% passes 90mm sieve
- 25-60% passes 63mm sieve
- 0-15% passes 37.5mm sieve
- 0-5% passes 19mm sieve

The limestone layer should be 1.2 metres thick and there should be approximately 0.5 metres of free board above the level of the limestone.

Underdrain Piping for Normal Operation

The piping from the AMD collection system will enter the LLB through a single vertical header along the upstream narrow dimension of the LLB. Perforations will begin below the level of the treatment media and will extend to the base of the system on 0.3 metre centres. Perforations will be two 2-cm diameter holes on each centre 90^{o} apart (5 locations with 2 perforations each).

The outlet from the LLB will be identical to the inlet header but placed on the other end of the pond (10 2-cm diameter holes along a vertical header). The outlet will pass through a V-junction pipe, with each pipe terminating in a flushing/settling pond.

Underdrain Piping Flushing System

Underdrain piping is placed between the bedding stone and the treatment media to enable efficient flushing of the system. The piping system will be divided into 4 quadrants or cells, each cell draining an area 10 metres long by 18 metres wide. Each cell will discharge through an individual outlet riser pipe. Seven perforated laterals will be installed in each cell on 1.5-metre centres and connected to a solid header with a sanitary-type tee. Perforations will be two 1.5-cm holes approximately 30^o from the top of the pipe. The perforation spacing will be 1.5 metres (equal to the lateral spacing). All underdrain piping should consist of 10-cm-diameter Schedule 40 PVC.

Each cell header will extend out of the LLB horizontally, pass through a V-junction, and terminate in the two flushing/settling ponds. Ball valves for operating the flushing system will be installed in each discharge pipe near the flushing/settling ponds. During normal operation the valves will be shut.

Flush/settling Ponds

Two flushing/settling ponds (#1 and #2) will be excavated adjacent to the LLB to capture precipitated compounds following treatment and flushing. Each pond will have a capacity of 380 cubic metres. During normal operation only pond #1 will be in use. Periodically, the system will be flushed into pond #2. Once the compounds have settled out of the water, the water will be siphoned into pond #1, and the accumulated sludge excavated and removed from the site. Once precipitated compounds have accumulated sufficiently in pond #1 through the course of normal operation, discharge from the system will be switched to pond #2 and pond #1 will serve as the flushing pond once the sludge has been removed.

The rate of accumulation of ferric and aluminium hydroxides ($Fe(OH)_3$ and $Al(OH)_3$) from the treatment system is estimated to be 5.3 tons per year (calculated using hydroxide molecular weights). The volume of sludge that would accumulate per year is difficult to estimate as it largely depends on the rate of settling.

To enhance settling of captured material, flocculant could be added to the settling ponds. The percent solids of sludge from AMD treatment systems is often assumed to be 5% (Computer Program AMD Treat Version 3.1). Using this value, the estimated accumulation of sludge is approximately 100 tons per year (approximately 100 cubic metres per year). It is recommended that the sludge is excavated from each settling pond once every two years or more often if necessary. We recommend that a benchtop study be completed to examine sludge density from the trial remediation systems.

Final Settling Pond

One final settling pond will be constructed following the two flushing/settling ponds. This pond will serve to capture any remaining compounds which have not settled out in ponds #1 or #2. This pond will also have a holding capacity of 380 cubic metres. Downstream of the final settling pond, the treated AMD will be returned to Herbert Stream.

Conclusion

Based on the results of the trial remediation systems installed at the Herbert Stream AMD on the Stockton Plateau, it is recommended that a horizontal limestone leaching bed with a vertical-flushing capability is constructed to treat the full flow of AMD from the Herbert Dam.

It is recommended that prior to construction of the full treatment system, any additional data from the ongoing operation of the trial treatment systems is evaluated. In addition, it is also recommended that an operation and maintenance report be prepared once the system has been constructed.

Long-term performance of an LLB treatment system has not been assessed in this work. While the design is for a minimum of 25 years, additional maintenance beyond normal operation and maintenance might be required on a medium term (2-10 years). This maintenance may include items such as backflushing of piping, replacement or repair of piping, or repair of geotextile liner.

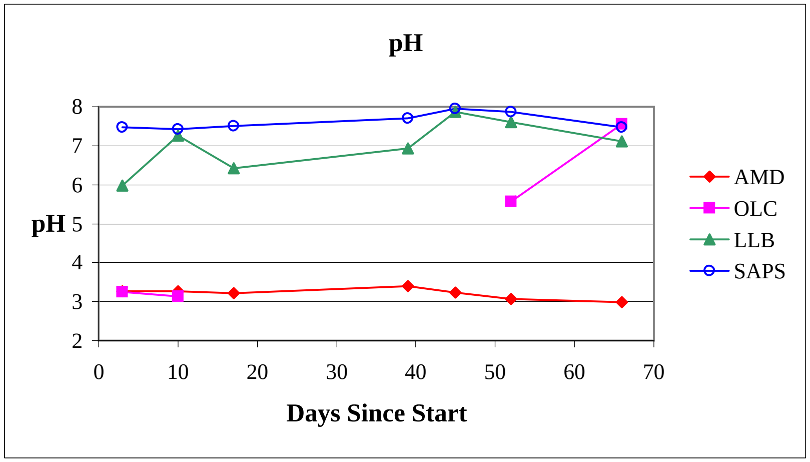
Appendix 1: Remediation Experiments at Herbert Stream

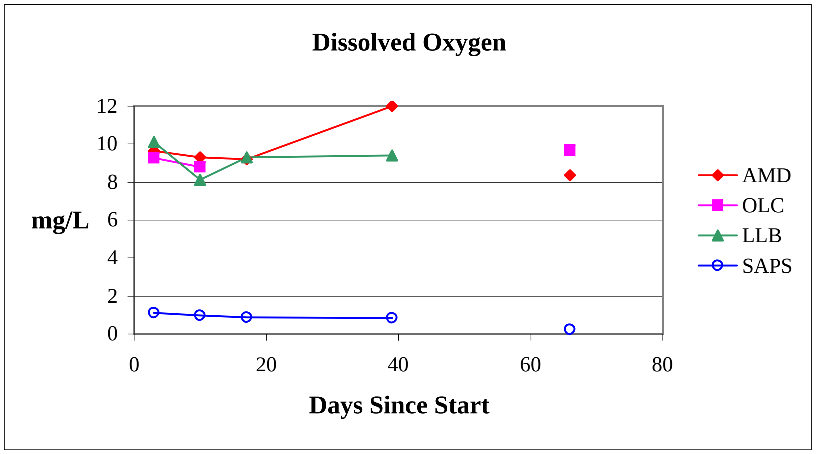
Analytical Results
Pilot AMD Remediation Systems - Herbert Stream

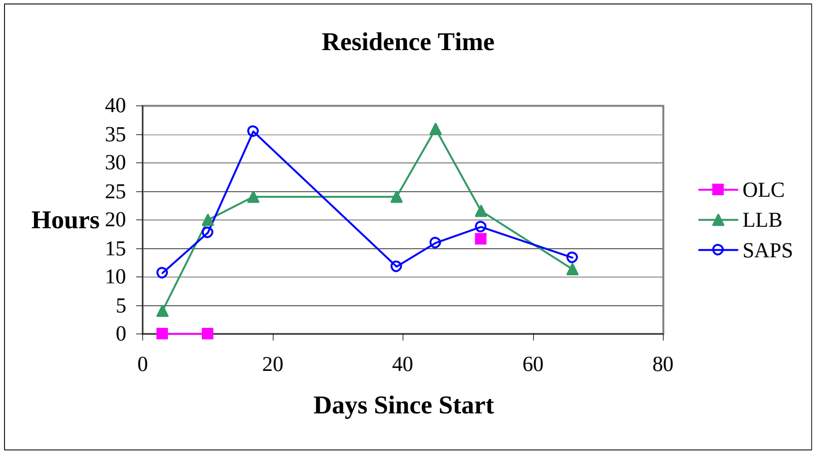
Location	Date	Days Operating	Acidity (at pH 4.5) (g/m^3 as $CaCO_3$)	Acidity (at pH 8.3) (g/m^3 as $CaCO_3$)	Alkalinity (g/m^3 as $CaCO_3$)	Sulphate (g/m^3)	Dissolved Calcium (g/m^3)	Dissolved Aluminium (g/m^3)	Dissolved Iron (g/m^3)	Dissolved Manganese (g/m^3)	Dissolved Nickel (g/m^3)
Untreated AMD	5/12/2005	0									
	8/12/2005	3	44	86	3	120	7.70	8.5	3.45	0.65	0.05
	15/12/2005	10	42	88	2	140	8.20	8.4	0.49	0.75	
	22/12/2005	17	48	92	2	140	7.70	7.6	0.75	0.710	
	13/01/2006	39	31	68	3	98	5.20	2.9	0.46	0.39	
	19/01/2006	45	42	90	3	133	62	8.4	1.35	0.53	
	26/01/2006	52	48	102	3	146	10	9.4	0.33	0.75	
	9/02/2006	66	38	106	3	150	10	8.5	1.20	0.92	
Open Limestone Channel (OLC)	5/12/2005	0									
	8/12/2005	3	42	90	3	125	7.80	8.2	3.51	0.64	0.05
	15/12/2005	10	42	88	2	145	8.50	8.2	0.39	0.74	
	22/12/2005	17									
	13/01/2006	39									
	19/01/2006	45									
	26/01/2006	52	-24	10	9	155	46	0.1	0.02	0.59	
	9/02/2006	66									
Limestone Leaching Bed (LLB)	5/12/2005	0									
	8/12/2005	3	-18	2	9	120	42.00	0.2	0.31	0.57	0.05
	15/12/2005	10	-28	-24	32	140	51.00	0.1	0.05	0.47	
	22/12/2005	17	-14	8	10	135	37.00	0.1	0.06	0.510	
	13/01/2006	39	-26	2	7	101	31	0.1	0.08	0.24	
	19/01/2006	45	-78	-40	78	88	57	0.4	0.08	0.04	
	26/01/2006	52	-90	-68	86	143	86	0.1	0.03	0.28	
	9/02/2006	66	-76	-14	52	134	66	0.1	0.04	0.58	
Diversion Well (DW)	5/12/2005	0									
	8/12/2005	0									
	15/12/2005	0									
	22/12/2005	0									
	13/01/2006	0									
	19/01/2006	6	44	90	3	137	7	9.0	0.74	0.52	
	26/01/2006	13									
	9/02/2006	27	44	108	3	143	12	8.6	1.14	0.93	
Successive Alkalinity Producing System (SAPS)	5/12/2005	0									
	8/12/2005	3	-88	-32	109	820	350.00	0.1	0.10	0.28	0.05
	15/12/2005	10	-96	-52	128	490	235.00	0.1	0.09	0.08	
	22/12/2005	17	-288	-98	364	800	355.0000	0.1	0.3900	0.790	
	13/01/2006	39	-82	-22	82	140	7.8	0.1	0.23	0.06	
	19/01/2006	45	-74	-38	78	96	60	0.1	0.19	0.03	
	26/01/2006	52	-94	-34	50	139	97	0.1	0.13	0.04	
	9/02/2006	66	-82	-2	80	154	84	0.1	0.11	0.21	

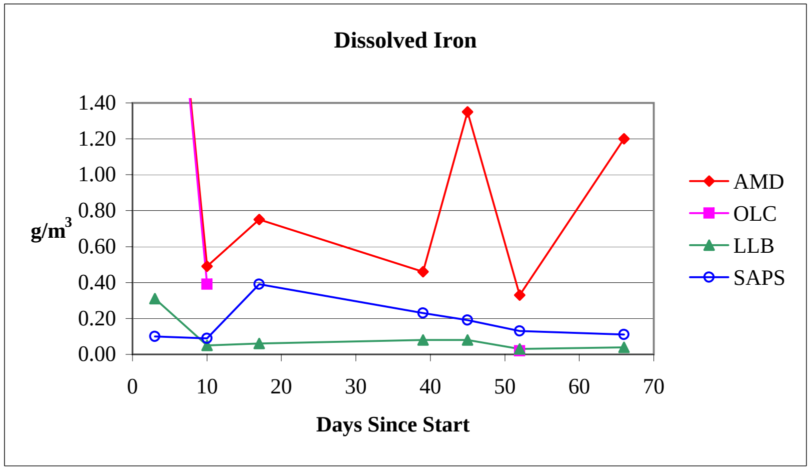
Field Data Results
Pilot AMD Remediation Systems - Herbert Stream

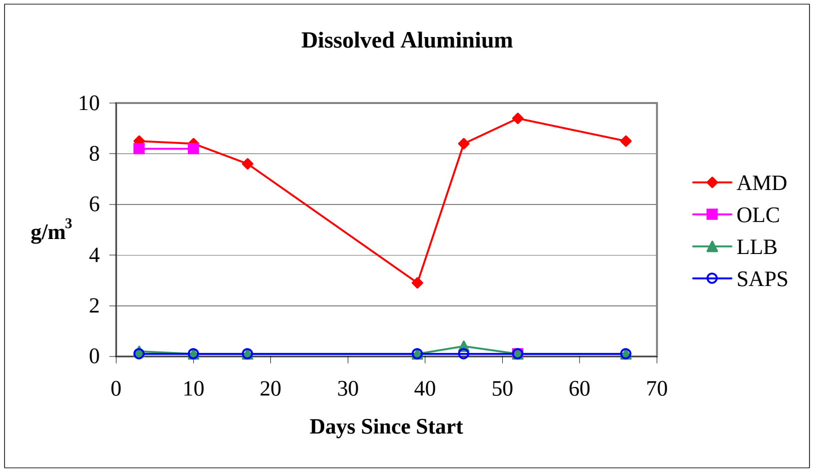
Location	Date	Days Operating	pH	Conductivity (µs/cm)	Dissolved Oxygen (mg/L)	Temperature (^oC)	Total Fe^{2+} (ferrous) (g/m^3)	Total Fe^{3+} (ferric) (g/m^3)	Fe^{3+} (percent)	Flow Rate (L/s)	Residence Time (hr)	Volume Treated (L)	Cummulative Volume Treated (L)	Mass of Al Removed (g)	Cummulative Mass of Al Removed (g)	Mass of Fe Removed (g)	Cummulative Mass of Fe Removed (g)	Mass of Mn Removed (g)	Cummulative Mass of Mn Removed (g)
	5/12/2005	0																	
	8/12/2005	3	3.27	440	9.65	8.2													
	15/12/2005	10	3.26	447	9.3	9.8													
Untreated AMD	22/12/2005	17	3.22	458	9.2	8.8													
	13/01/2006	39	3.4	250	12	11													
	19/01/2006	45	3.23	443		9.2													
	26/01/2006	52	3.07	444		10.6													
	9/02/2006	66	2.98	363	8.36	8.9	0.54	3.86	88%										
	5/12/2005	0																	
	8/12/2005	3	3.25	429	9.26	8.2				0.75	0.03	194400	194400	58.32	58.32	-11.66	-11.66	1.94	1.94
	15/12/2005	10	3.14	463	8.8	8.3				0.6	0.03	362880	557280	72.58	130.90	36.29	24.62	3.63	5.57
Open Limestone	22/12/2005	17								0									
Channel (OLC)	13/01/2006	39																	
	19/01/2006	45																	
	26/01/2006	52	5.56	308		15.3				0.0013	16.67	756	558036	7.03	7.03	0.23	0.23	0.12	0.12
	9/02/2006	66	7.56	281	9.67	11.8	0.11			0									
	5/12/2005	0																	
	8/12/2005	3	5.97	288	10.12	11				0.015	4.00	3888	3888	32.27	32.27	12.21	12.21	0.31	0.31
	15/12/2005	10	7.26	358	8.14	13.5				0.003	20.00	1814	5702	15.06	47.33	0.80	13.01	0.51	0.82
Limestone Leaching	22/12/2005	17	6.42	256	9.3	12				0.0025	24.00	1512	7214	11.34	58.67	1.04	14.05	0.30	1.12
Bed (LLB)	13/01/2006	39	6.93	225	9.4	13.5				0.0025	24.00	4752	11966	13.31	71.98	1.81	15.86	0.71	1.83
	19/01/2006	45	7.87	361		11.3				0.0017	36.00	864	12830	6.91	78.89	1.10	16.95	0.42	2.26
	26/01/2006	52	7.6	379		11.5				0.0028	21.56	1683	14514	15.66	94.54	0.51	17.46	0.79	3.05
	9/02/2006	66	7.11	363		16	0.19	1.06	85%	0.0053	11.40	6366	20880	53.48	148.02	7.38	24.84	2.16	5.21
	5/12/2005	0																	
	8/12/2005	0																	
	15/12/2005	0																	
Diversion Well	22/12/2005	0																	
(DW)	13/01/2006	0																	
	19/01/2006	6	3.34	400		9.1				3		1555200	1555200	-13996.80	-13996.80	-1150.85	-1150.85	-808.70	-808.70
	26/01/2006	13	3.2	444		11.6				3		1814400	3369600	181.44	-13815.36	36.29	-1114.56	1070.50	261.79
	9/02/2006	27	3.01	358	9.16	8.9	0.57	3.73	87%	3		3628800	6998400	-31207.68	-45023.04	-4136.83	-5251.39	-3374.78	-3112.99
	5/12/2005	0																	
	8/12/2005	3	7.47	1594	1.1	11				0.005	10.67	1296	1296	10.89	10.89	4.34	4.34	0.48	0.48
Successive	15/12/2005	10	7.42	1165	0.98	13.3				0.003	17.78	1814	3110	15.06	25.95	0.73	5.07	1.22	1.70
Alkalinity	22/12/2005	17	7.51	1574	0.89	11.2				0.0015	35.56	907	4018	6.80	32.75	0.33	5.39	-0.07	1.62
Producing System	13/01/2006	39	7.71	465	0.84	13.5				0.0045	11.76	8617	12635	24.13	56.88	1.98	7.38	2.84	4.47
(SAPS)	19/01/2006	45	7.95	370		11.9				0.0033	16.00	1728	14363	14.34	71.22	2.00	9.38	0.86	5.33
	26/01/2006	52	7.87	504		14.5				0.0029	18.71	1724	16086	16.03	87.25	0.34	9.73	1.22	6.55
	9/02/2006	66	7.47	345	0.24	11.2	0.37	0.00	0%	0.004	13.33	4838	20925	40.64	127.89	5.27	15.00	3.44	9.99

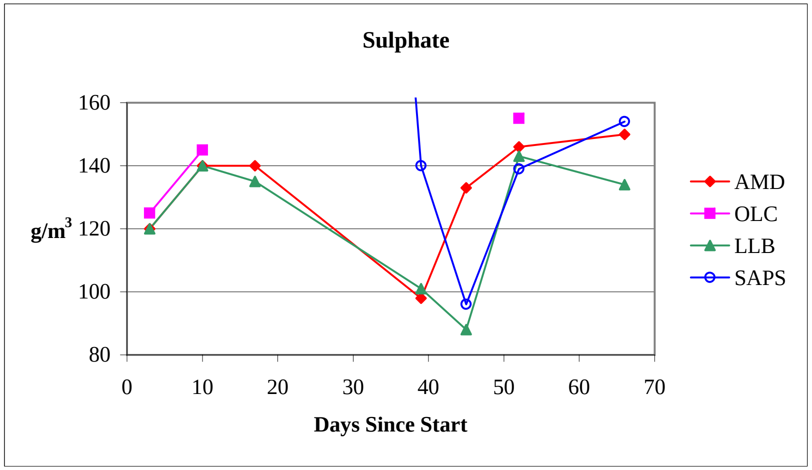

pH
pH
8
7
6
5
4
3
2
0
10
20
30
40
50
60
70
Days Since Start
AMD
OLC
LLB
SAPS

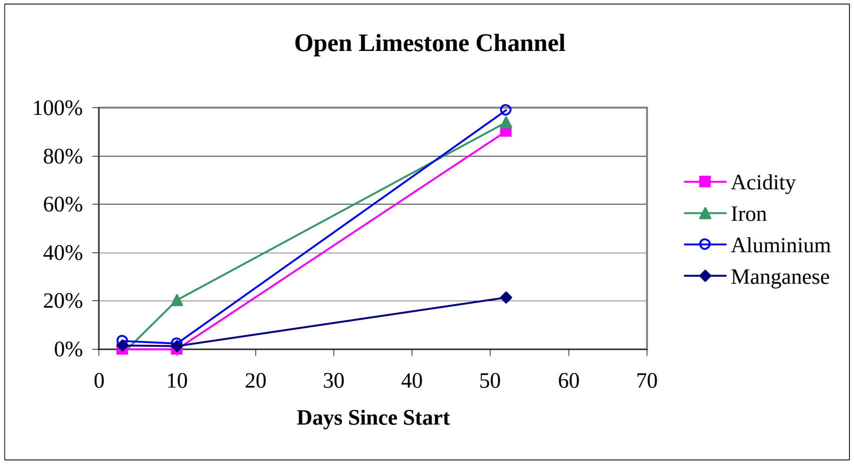

Dissolved Oxygen
mg/L
12
10
8
6
4
2
0
0
20
40
60
80
Days Since Start
AMD
OLC
LLB
SAPS

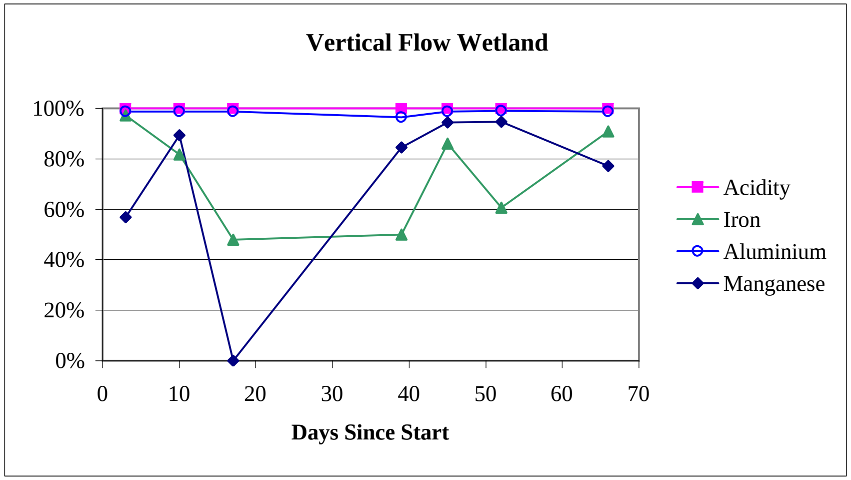

Residence Time
Hours
40
35
30
25
20
15
10
5
0
0
20
40
60
80
Days Since Start
OLC
LLB
SAPS

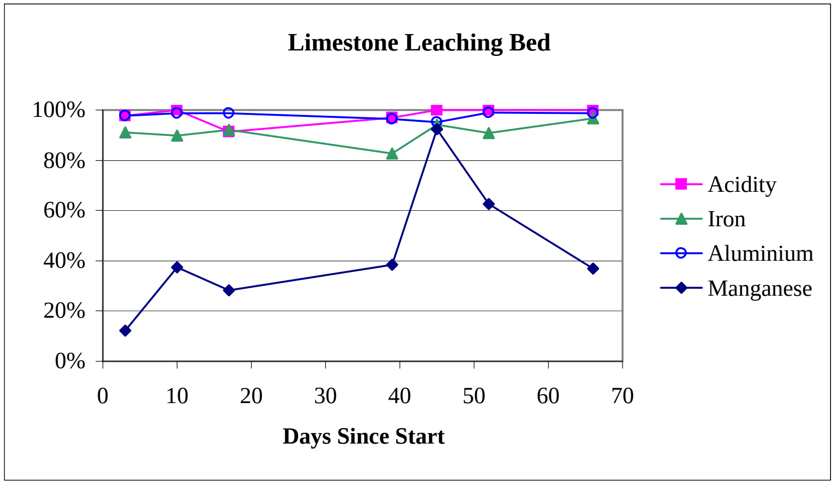

Dissolved Iron
g/m3
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
50
60
70
Days Since Start
AMD
OLC
LLB
SAPS


Dissolved Aluminium
g/m3
10
8
6
4
2
0
0
10
20
30
40
50
60
70
Days Since Start
AMD
OLC
LLB
SAPS


Sulphate
g/m3
160
140
120
100
80
0
10
20
30
40
50
60
70
Days Since Start
AMD
OLC
LLB
SAPS


Open Limestone Channel
100%
80%
60%
40%
20%
0%
0
10
20
30
40
50
60
70
Days Since Start
Acidity
Iron
Aluminium
Manganese


Vertical Flow Wetland
100%
80%
60%
40%
20%
0%
0
10
20
30
40
50
60
70
Days Since Start
Acidity
Iron
Aluminium
Manganese


Limestone Leaching Bed
100%
80%
60%
40%
20%
0%
0
10
20
30
40
50
60
70
Days Since Start
Acidity
Iron
Aluminium
Manganese

Limestone Leaching Bed was flushed into a holding tank on 19 January 2006

Data:

20 minutes to drain
Water height in holding tank after draining = 260 mm
Total tank height = 890 mm
Tank diameter = 570 mm
Total tank volume = 225 L

Steps in the analysis of this data:
1. Determine volume in holding tank
2 Compare volume flushed to what expected to be held by LLB
3. Determine mass of metals in holding tank
4. Determine mass of metals captured by LLB over time frame (inlet total minus outlet total)
5. Determine mass not flushed out (in mg and in percentage of removal from AMD)
6. Determine residence time in holding tank
7. Determine effectiveness of holding tank

1. Determine volume in holding tank

m^3	L
0.07	66.3

2 Compare volume flushed to what expected to be held by LLB

	Limestone thickness (cm)	Thickness (m)	Porosity	LLB area=(m2)	void volume (m3)	volume (L)
Original	59	0.59	0.50	0.73	0.22	**216**
Revised !	59	0.59	0.3	0.73	0.13	129
	59	0.59	0.25	0.73	0.11	108
	59	0.59	0.2	0.73	0.09	86
	59	0.59	0.15	0.73	0.06	**65**

3. Determine mass of metals in holding tank

			Volume in tank (m^3)	Mass in grams
Aluminium - total	g/m^3	100	0.0663	6.63
Iron - total	g/m^3	133	0.0663	8.82
Manganese - total	g/m^3	3.4	0.0663	0.23

4. Determine mass of metals captured by LLB over time frame (inlet total minus outlet total)

Assuming that only part of the unit flushed and that porosity is more like 0.25
Then the following table summarises the mass of contaminants removed:
Volume of void space: 108 Litres

DISSOLVED ONLY

Date	Flow Rate (L/s)	Residence Time (hr)	Volume Treated (L)	Cummulative Volume Treated (L)	Mass of Al Removed (g)	Cummulative Mass of Al Removed (g)	Mass of Fe Removed (g)	Cummulative Mass of Fe Removed (g)	Mass of Mn Removed (g)	Cummulative Mass of Mn Removed (g)
5/12/2005										
8/12/2005	0.015	2	3888	3888	32.27	32.27	12.21	12.21	0.31	0.31
15/12/2005	0.003	10	1814	5702	15.06	47.33	0.80	13.01	0.51	0.82
22/12/2005	0.0025	12	1512	7214	11.34	58.67	1.04	14.05	0.30	1.12
13/01/2006	0.0025	12	4752	11966	13.31	71.98	1.81	15.86	0.71	1.83
19/01/2006	0.0017	18	864	12830	6.91	**78.89**	1.10	**16.95**	0.42	**2.26**

	Total Metals:					
5/12/2005	AMD-Al	LLB-Al	AMD-Fe	LLB-Fe	AMD-Mn	LLB-Mn
8/12/2005	8.5	5.5	3.74	4.54	0.67	0.60
15/12/2005	8.4	3.1	4.66	1.43	0.75	0.53
22/12/2005	7.8	3.6	4.53	1.74	0.72	0.55
13/01/2006	2.9	1.4	2.45	1.10	0.39	0.26
19/01/2006	9.1	1.4	3.54	0.51	0.54	0.05

TOTAL ONLY

Date	**Flow Rate (L/s)**	**Residence Time (hr)**	**Volume Treated (L)**	**Cummulative Volume Treated (L)**	**Mass of Al Removed (g)**	**Cummulative Mass of Al Removed (g)**	**Mass of Fe Removed (g)**	**Cummulative Mass of Fe Removed (g)**	**Mass of Mn Removed (g)**	**Cummulative Mass of Mn Removed (g)**
5/12/2005										
8/12/2005	0.015	2	3888	3888	11.66	11.66	-3.11	-3.11	0.27	0.27
15/12/2005	0.003	10	1814	5702	9.62	21.28	5.86	2.75	0.40	0.67
22/12/2005	0.0025	12	1512	7214	6.35	27.63	4.22	6.97	0.26	0.93
13/01/2006	0.0025	12	4752	11966	7.13	34.76	6.42	13.38	0.62	1.55
19/01/2006	0.0017	18	864	12830	6.65	**41.41**	2.62	**16.00**	0.42	**1.97**

Total Mass of Contaminants Captured		
Aluminium	41.41	grams
Iron	16.00	grams
Manganese	1.97	grams

5. Determine mass not flushed out (in mg and in percentage of removal from AMD)

	Captured (g)	Flushed (g)	Retained (g)	% flushed
Aluminium	41.41	6.63	34.78	16%
Iron	16.00	8.82	7.18	55%
Manganese	1.97	0.23	1.74	11%

6. Determine residence time in holding tank

7. Determine effectiveness of holding tank

volume in holding tank below outlet

m^3	L
0.19	186

Date	Flow Rate (L/s)	Residence Time (hr)	Aluminium			Iron			Manganese		
			Total	Dissolved	% in dissolved form	Total	Dissolved	% in dissolved form	Total	Dissolved	% in dissolved form
8/12/2005	0.015	3									
15/12/2005	0.003	17									
22/12/2005	0.0025	21									
13/01/2006	0.0025	21									
19/01/2006	0.0017	31									
26/01/2006	0.0028	19									
9/02/2006	0.0053	10	2.5	0.1	4%	1.25	0.04	3%	0.78	0.58	74%

CONCLUSIONS

1. Flushing mobilised 10 to 50% of total metal mass removed
2. Volume flushed 1/3 of expected volume in system
   Means porosity really 15-25%, not 50%
   Means residence time in system only 10-18 hours
3. Residence time in holding tank of 10 hours still allows 26-97% contaminants in suspended form to flow out
4. Need more rapid flushing, more often + longer residence time in holding tank (20 hours?)